Geology of the Bald Knob Quadrangle Ferry and Okanogan Counties, Washington

GEOLOGICAL SURVEY BULLETIN 1161-F

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By MORTIMER H. STAATZ

CONTRIBUTIONS TO GENERAL GEOLOGY

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Geology of 198 square miles in the central part of the Okanogan Highlands, Washington

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GEOLOGY OF THE BALD KNOB QUADRANGLE, FERRY AND OKANOGAN COUNTIES, WASHINGTON

By Mortimer H. Staatz

ABSTRACT

The Bald Knob quadrangle is in the central part of the Okanogan Highlands in eastern Okanogan and western Ferry Counties, Wash., and is in the north-central part of the Colville Indian Reservation, 20 miles north of Coulee Dam.

Rocks range in age from either late Paleozoic or early Mesozoic to Pleistocene. The northwestern part of the quadrangle is underlain by Mesozoic batholithic rocks and the eastern and southern parts by early Tertiary volcanic rocks. An irregular, discontinuous zone as much as 3 miles wide that lies between these two major rock types contains metamorphosed sedimentary, metamorphosed igneous, and igneous rocks of late Paleozoic and Mesozoic age. Pleistocene glacial deposits are irregularly distributed over the entire quadrangle. The oldest rocks in the quadrangle are metamorphosed igneous and unfossiliferous metamorphosed sedimentary rocks of probable Permian or Triassic age. These rocks form three partial sequences in the northern, central, and southwestern parts of the quadrangle. Although the relative ages of these rocks to one another in each area is known, the relative ages of one sequence to the next is not.

The oldest rock in the northern part of the quadrangle is greenstone. This rock is overlain by phyllitic quartzite at least 6,100 feet thick, the upper 2,300 feet of which contains interbeds of hornblende schist and chlorite schist. This unit is overlain by a complexly folded unit of phyllite, which commonly contains quartzite lenses. The phyllite unit is in turn overlain by a unit of graywacke, about 7,000 feet thick, which contains interbeds of phyllite in its upper part. In the central part of the quadrangle, the metamorphosed sedimentary rocks are represented by a complexly folded black shale, and in the southwestern part of the quadrangle, the oldest metamorphosed sedimentary rock is a mica-quartz schist, which contains numerous interbeds of quartzite. This unit is overlain by a black shale unit at least 2,300 feet thick which contains a 450-foot layer of impure limestone about 500 feet above its base. Above the black shale is a unit of fine-grained quartzite. Most of the metamorphosed sedimentary units contain a few widely scattered beds of impure limestone. Two intrusive rocks are found in this area: metadiorite, which occurs as many small bodies intruded into the metamorphosed sedimentary rocks throughout the quadrangle; and granodiorite porphyry, which occurs as a conspicuous east-trending dike. The igneous rocks underwent retrograde metamorphism in the green schist facies but never reached equilibrium as did the rocks of sedimentary origin.

The oldest unmetamorphosed rock is diorite, which forms an irregular body of about 2 square miles in the southwestern part of the quadrangle and part of a much larger body in the southeast corner. Batholithic rocks of Mesozoic age were intruded into at least the eastern half of the Colville Indian Reservation and consist chiefly of quartz monzonite and lesser amounts of quartz diorite and granodiorite. In the Bald Knob quadrangle, these rocks crop out in the northwestern one-third of the area and probably underlie most of the other rocks at depth. Adjacent to the batholith the older rocks are crumpled and contact metamorphosed. Serpentine occurs in several lenticular bodies that intrude the quartzite and black shale units in the southwest part of the quadrangle.

More than half the Bald Knob quadrangle is underlain by volcanic and related rocks of early Tertiary age. The oldest unit is the Eocene(?) O'Brien Creek Formation, a relatively thin unit composed chiefly of tuff and a little breccia. This unit pinches out to the south, as it is not found in the southern half of the quadrangle. The O'Brien Creek Formation is overlain conformably by the Sanpoil Volcanics of Eocene or Oligocene age, a thick series made up largely of rhyodacite and quartz latite flows. Interbedded tuffs occur in this formation but are found chiefly in the southern half of the quadrangle. Rhyodacite and quartz latite occur also as dikes and small intrusives. These rocks, called the Scatter Creek Rhyodacite of Eocene or Oligocene age, are the intrusive equivalent of the flows of the Sanpoil Volcanics.

The youngest rocks in the Bald Knob quadrangle are glacial deposits of Pleistocene age. The deposits consist of till, kame terraces, and glacial lake deposits. The till, which is thickest in the valleys, once blanketed the entire quadrangle. The kame terraces formed discontinuously in a few of the larger valleys, and the lake deposits were formed behind an ice dam in the lower part of Gold Creek.

The rocks of the Bald Knob quadrangle have been deformed at least twice, and those in areas adjacent to the Colville batholith have been deformed a third time. The earliest known period of deformation occurred after the deposition of the metamorphosed sedimentary rocks but prior to the intrusion of the diorite. This period probably coincided with that of regional metamorphism; in addition to a well-defined cleavage, the deformation formed numerous northwest-trending faults and northward-trending folds in the metamorphosed sedimentary and metamorphosed igneous rocks. The second period of deformation started in Eocene(?) time soon after the earliest volcanic rocks were erupted and continued until at least Miocene time, after the last of volcanics had been erupted. The rocks were again both faulted and folded, and during this period long northeast-trending faults formed. These faults bound the Republic graben, a major structural feature in northeast Washington. The graben extends for a least 50 miles, and within the Bald Knob quadrangle it is 9.5 miles wide. The sinking of the graben was caused by the weight of the thick sequence of volcanic rocks deposited on its top coupled with the removal of the material that made up these volcanic rocks from beneath it.

The topography of Bald Knob quadrangle consists of rounded, moderately undulating upland surfaces cut by steep-walled valleys. The uplands represent a fairly mature stage of erosion that started to form soon after the Tertiary volcanic rocks were deposited. The valleys represent a youthful stage of erosion that formed as a result of renewed uplift prior to Pleistocene glaciation. Pleistocene glaciers widened some of the valleys, reversed the grade in some streams, filled in upland basins, and cut many irregular knobs along the ridges.

In the central part of the Bald Knob quadrangle is the Park City mining district—a small lead-silver district that was developed chiefly in the early 1900's. Metalliferous deposits in this district occur in quartz veins along small faults and in mineralized shear zones. The deposits, which have extremely diverse attitudes, are small and irregular but are fairly high grade. They occur either along or adjacent to the contact of the Colville batholith and the metamorphosed sedimentary rocks. Pyrite is the most common sulfide, and argentiferous galena is the principal ore mineral. The other common sulfides are sphalerite, chalcopyrite, and pyrrhotite. The ore bodies were formed by fluids derived from the batholith.

In the southwestern part of the Bald Knob quadrangle, small low-grade chromium-nickel prospects are found in or adjacent to serpentine bodies. Along Strawberry Creek and in the main streams below it are small gold placer deposits, which were mined in the early 1900's.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Bald Knob quadrangle is in the central part of the Okanogan Highlands in Ferry and Okanogan Counties in northeastern Washington. It lies between lat 48°15′ and 48°30′ N. and long 118°45′ and 119°00′ W. and is an area of 198 square miles (fig. 1). All but a strip 1.2 miles wide along the quadrangle's northern boundary lies within the Colville Indian Reservation. The northeast corner of the quadrangle is 10 miles south of the town of Republic, the southwest corner of the quadrangle is 6 miles north of the town of Nespelem and 20

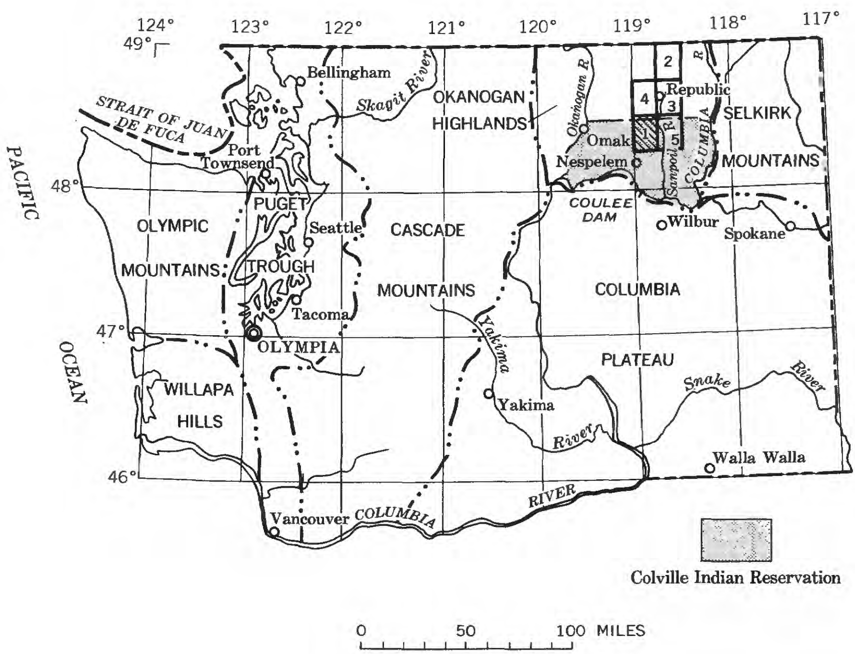


FIGURE 1.—Index map of Washington showing physiographic divisions and location of the Bald Knob and neighboring quadrangles. 1, Bald Knob quadrangle; 2, Curlew quadrangle; 3, Republic quadrangle; 4, Wauconda quadrangle; and 5, Seventeenmile Mountain quadrangle.

miles north of Coulee Dam, and the southeast corner is 71 miles northwest of Spokane. The nearest railhead, which is on the Great Northern Railway, is at the town of Republic.

Roads are in general poor in the Bald Knob quadrangle, and habitations are few. State Highway 4, the nearest paved highway, connects the town of Republic with Wilbur and Spokane (fig. 1) and follows the Sanpoil River, which flows just east of the quadrangle. In the northeast corner of the quadrangle (pl. 1), near the junction of the Sanpoil River and the West Fork of the Sanpoil River, one of its main tributaries, the highway curves into the mapped area for two-thirds of a mile. The junction of the two streams is called West Fork, which contains a gas station and lodge. One farmhouse in the neighborhood of West Fork and five farmhouses in the southwest corner of the quadrangle are the only other habitations. In addition to roads shown on plate 1, small semipermanent lumber, mining, and farm roads aid access to some other areas. Driving vehicles with low road clearance is hazardous over any of the roads in the quadrangle other than the main route from West Fork to the southwest corner of the quadrangle.

TOPOGRAPHY AND DRAINAGE

The Bald Knob quadrangle is centrally located within the Okanogan Highlands, which is a composite group of mountains that trend generally north. In Washington the Okanogan Highlands occupy an area of about 90 miles (east-west) by 75 miles (north-south) (Patty, 1921, p. 29). This region is characterized by rounded flat-topped mountains and steep-walled valleys. The highest point in the quadrangle is at an altitude of 5,855 feet on Strawberry Mountain in the northwestern part of the quadrangle, and the lowest point is at an altitude of about 1,900 feet on the Nespelem River in the southwest corner of the quadrangle. Although only four peaks, all in the northwest corner of the quadrangle, exceed 5,000 feet in altitude, more than 40 peaks and ridges are greater than 4,000 feet in altitude; in general, the altitudes of the mountains decrease from north to south.

Many permanent streams and several small lakes are found in the Bald Knob quadrangle (pl. 1). All the streams eventually flow south into the Columbia River by way of two main tributaries—the Sanpoil and Nespelem Rivers (fig. 1). The Sanpoil River reaches the Columbia 19 miles above Coulee Dam, and the Nespelem River reaches the Columbia 14 miles below the dam. The streams in the mapped area reach the main tributaries by several different routes. Streams in northwestern part of the quadrangle flow westward and northeastward out of the quadrangle into the West Fork of the Sanpoil

River; the streams in the central part of the quadrangle flow into Gold Creek, which joins the West Fork of the Sanpoil about 2½ miles west of West Fork; and the streams in the eastern part of the qaudrangle flow eastward directly into the Sanpoil River. The streams in the southwestern part of the quadrangle flow into the Nespelem River.

The largest lake in the mapped area, Little Owhi Lake in the southern end of the quadrangle is 2,300 feet by 1,100 feet. The other principal lakes are Gold Lake in the central part of the quadrangle and Long Lake in the northern part. In addition, numerous small lakes—many not shown on the map—are found throughout the Bald Knob quadrangle. The lakes are of three types: Those in valley bottoms dammed by ground moraine, such as Long, Little Owhi, and Gold Lakes; those dammed by beavers; and those on ridge tops in little hollows scooped out by the glacier.

VEGETATION

A thick conifer forest covers the Bald Knob quadrangle except for the broad flat-topped ridges underlain by volcanic rocks in the eastern part of the area and the broad valleys and a few of the low ridges in the southwestern part. Hardwoods are also present in some places, most commonly along the valley bottoms and on south-facing slopes in the southern part of the area. The three most common trees are Douglas-fir (*Pseudotsuga taxifolia*), western larch (*Larix occidentalis*), and western yellow pine (*Pinus ponderosa*). Douglas-fir and western larch are commonest in the northern and central parts of the quadrangle; and yellow pine, in the dry lower southern part. Other conifers include lodgepole pine (*Pinus contorta* var. *latifolia*), which is common in a few flat basins such as on Strawberry Creek and 1½ miles east of Gold Lake, and Engelmann spruce (*Picea engelmanni*), which is found in some of the higher valleys. The hardwoods include Sitka willow (*Salix sitchensis*), California alder (*Alnus rhombifolia*) western trembling aspen (*Populus tremuloides* var. *aurea*), black cottonwood (*Populus trichocarpa*), balsam poplar (*Populus balsamifera*), dwarf maple (*Acer glabrum*), and paper birch (*Betula papyrifera*). In scattered localities, lodgepole pine is cut for poles, and Douglas-fir, larch, yellow pine, and spruce are cut for lumber; the hardwoods are not used.

PURPOSE AND SCOPE OF REPORT

The northeast corner of the State of Washington is geologically one of the most poorly known areas in the United States. The U.S. Geological Survey is working out the stratigraphic sequence and structure of the rocks in the area; and this paper, which describes the rock types, structure, geomorphology, geologic history, and mineral deposits of an area in the region, is a part of the study.

In the past, important production of the base metals in northeast Washington has come from mines near Metaline and Northport; and production of the precious metals, from mines near Republic. In the Bald Knob quadrangle no important ore deposits have been found, although the small Park City mining district, which is one of four small silver-lead mining districts in the Colville Indian Reservation (Pardee, 1918), is located in the central part of the quadrangle. This report is a step toward better knowledge of the mineralization in the area; without such knowledge, finding new mines will remain a matter of luck.

PREVIOUS WORK

Most of the previous work referring to the Bald Knob quadrangle is in reports on various metal deposits in Washington. Collier (1907, p. 68–69) made brief mention of gold placer deposits at West Fork on the Sanpoil River and on Gold and Strawberry Creeks. Bancroft (1914, p. 203–210) described the better developed properties in the Park City mining district. Pardee (1918) prepared a reconnaissance geologic map of the Colville Indian Reservation on a scale of 1:250,000 and a more detailed map of about 52 square miles in the vicinity of the Park City mining district on a scale of 1:62,500. These maps show the gross distribution of the rock types but show neither the geologic structure nor the subdivided metamorphosed sedimentary rocks, which were mapped undifferentiated as the Covada Group. Pardee (1918, p. 86–103) also described the geology of the Park City mining district and gave data on deposits not previously reported by Bancroft. Patty (1921, p. 189–192) gave a résumé on the metal mines of Washington and included a brief description of several prospects in the Park City district.

FIELDWORK AND ACKNOWLEDGMENTS

The geology of the Bald Knob quadrangle was mapped during the summers of 1957, 1958, and 1959. In 1957 I was efficiently assisted by Henry L. Brooks, in 1958 by Kimball Q. McDonald, and in 1959 by Ernest H. Carlson. All geologic mapping was done on enlargements of the topographic map of the quadrangle. Glacial debris covers the greater part of the bedrock except in areas underlain by volcanic rocks, where most of the glacial debris has been eroded. Hence, contacts between bedrock units are inferred in many places. The geologic map (pl. 1) is principally a bedrock map, and glacial deposits are distinguished only where they are wider than about 500 feet.

During the first 2 years of fieldwork, S. J. Muessig, R. L. Parker, and J. A. Calkins of the U.S. Geological Survey were mapping in the Republic, Wauconda, and Curlew quadrangles (fig. 1). Discussions in the field were of great help in solving many of our mutual problems. Thanks are due to Gary C. Curtin for about half of the microdrawings of the various rock types used in this paper.

I am also indebted to the Bureau of Indian Affairs, especially to Floyd H. Phillips, Superintendent of the Colville Agency, and to John Barnard, for many courtesies extended.

ROCK UNITS

In general, the Bald Knob quadrangle is underlain by Tertiary volcanic rocks in the southeastern half and batholithic rocks in the northwestern half (pl. 1). Between these two areas is an irregular northeast-trending zone, as much as 3 miles wide, of metamorphosed sedimentary, metamorphosed igneous, and igneous rocks.

The oldest rocks are the metamorphosed sedimentary rocks. Although no fossils were found in these rocks, similar rocks in the Republic and Curlew quadrangles contain Permian and Triassic fossils (S. J. Muessig, oral communication, 1958). The metamorphosed sedimentary rocks consist of several thick sequences of clastic rocks that include phyllite, phyllitic quartzite, graywacke, shale, quartzite, and schist. Interbedded in these rocks in a few widely scattered places are thin layers or lenses of impure limestone. The metamorphosed sedimentary rocks are underlain in the northern part of the quadrangle by a thick layer of greenstone. These rocks are a part of a eugeosynclinal suite that is younger than Cambrian and older than Cretaceous in northeastern Washington.

Several kinds of igneous rocks intrude these eugeosynclinal rocks. The oldest of the igneous rocks were intruded as small bodies prior to regional metamorphism and are now metadiorite. Two stocks of diorite, a batholith of quartz monzonite and related rocks, and several generally lenticular bodies of serpentine were intruded after metamorphism.

Volcanic rocks of early Tertiary age cover approximately the southeastern half of the quandrangle (pl. 1). The oldest unit, the Eocene(?) O'Brien Creek Formation, which consists mostly of air-laid tuff, is overlain by the Sanpoil Volcanics, which consists chiefly of a thick series of rhyodacite and quartz latite flows interbedded in places with a little tuff. Many dikes and small intrusive bodies were intruded into the metamorphosed sedimentary and batholithic rocks. These rocks are called the Scatter Creek Rhyodacite and are the intrusive equivalent of the Sanpoil Volcanics.

Glacial deposits of Pleistocene age consist of till, kame terraces, and glacial lake deposits. Till at one time covered the entire quadrangle; though the valleys still contain thick deposits, some of the till has been eroded from the uplands. Kame terraces form discontinuous benches along some of the bigger valleys, and a glacial lake deposit is exposed in places along the lower part of Gold Creek.

METAMORPHOSED SEDIMENTARY ROCKS

Metamorphosed sedimentary rocks crop out in a discontinuous zone, 1½–3 miles wide, trending north-northeastward through the center of the Bald Knob quadrangle (pl. 1). In general, the rocks of the zone are intruded by or faulted against rocks of the Colville batholith on the northwest and are overlain by the Sanpoil Volcanics on the southeast. The metamorphosed sedimentary rocks have been subjected to low-grade metamorphism and consist of phyllite, quartzite, graywacke, shale, limestone, and mica-quartz schist. Together with greenstone they make up the Covada Group (Pardee, 1918, p. 20–27). Because the metamorphosed sedimentary rocks in the Bald Knob quadrangle occur as distinct lithologic types showing a structural unity, they are divided into separate units on plate 1.

The metamorphosed sedimentary rock units form three partial sequences in three parts of the quandrangle and are separated from each other by faults or igneous rocks. Unfortunately, the correlations between sequences are not known because no identifiable fossils have been found and none of the units found in any one area is repeated in any other area. Hence, the metamorphosed sedimentary rocks are grouped according to the areas in which they occur and are described according to relative age within that area.

ROCKS IN THE NORTHERN PART OF THE QUADRANGLE

The metamorphosed sedimentary rocks discussed in this section include all those found between the northern border of the quadrangle and the southern boundary of T. 34 N. (pl. 1). These rocks are divided into three stratigraphic units: phyllitic quartzite, phyllite, and graywacke.

PHYLLITIC QUARTZITE

The phyllitic quartzite in the Bald Knob quadrangle forms a north-trending band about 1 mile by 3 miles. This band, which is cut off on the south by the Long Lake fault, occurs on both sides of the West Fork of the Sanpoil River and extends northward into the adjoining Wauconda quadrangle.

The phyllitic quartzite has a uniform northerly strike and a steep easterly dip. It overlies greenstone, apparently conformably. In most places the phyllitic quartzite and the overlying phyllite units are in fault contact, but in one place they appear to be conformable.

The phyllitic quartzite is at least 6,100 feet thick and consists for the most part of a fine-grained light-gray quartzite containing thin partings of phyllite. Many partings are paper thin, although in some places beds of phyllite are as much as 1 foot thick. The quartzite is made up of sutured quartz grains averaging approximately 0.2 mm in diameter. The phyllitic partings consist of small grains of quartz, biotite, sericite, and less than 1 percent tourmaline.

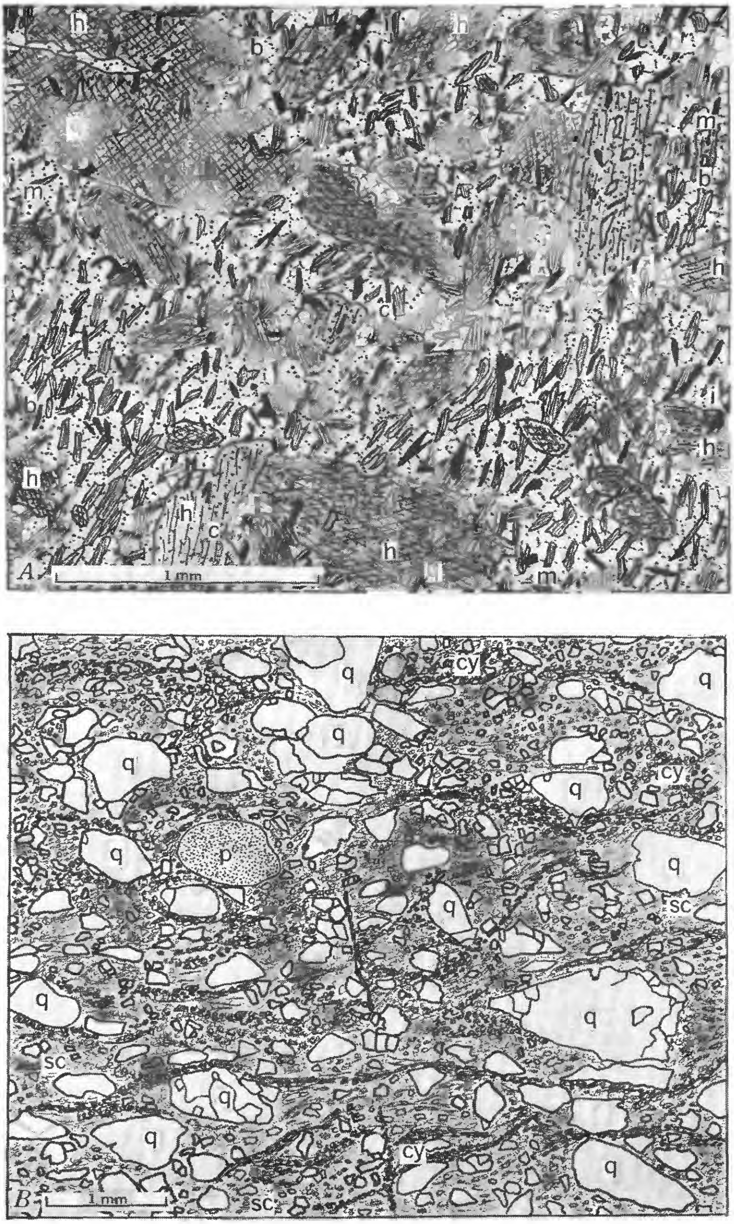
The upper 2,300 feet of this unit contains thick interbeds of a green calcareous chlorite-rich or hornblende-rich schist. Just north of the West Fork of the Sanpoil River this schist is rich in chlorite, but northward it grades into a hornblende-rich (fig. 2*A*) variety, which has a larger grain size. A specimen of schist from a quarter of a mile north of the West Fork of the Sanpoil River contained 40 percent chlorite, 36 percent quartz, 14 percent calcite, 8 percent biotite, 1 percent plagioclase, and 1 percent sphene; a specimen from the northern border of the quadrangle was estimated to contain 40 percent hornblende, 36 percent quartz, 10 percent biotite, 5 percent ilmenite, 4 percent calcite, 3 percent plagioclase, 2 percent chlorite, and traces of apatite and sericite. The change from south to north is mainly from a lower to a higher grade metamorphic rock in which chlorite and calcite change to hornblende. The higher grade rock formed probably from the lower grade rock by contact metamorphism from an underlying and hidden protuberance of the Colville batholith. Evidence for this mode of formation is the random orientation of the hornblende on an older foliation preserved by grains of biotite and ilmenite, indicating that the hornblende was formed later under nonstress conditions (fig. 2*A*).

A thin bed of impure limestone breccia about 100 feet thick is found near the base of the section. As this bed is exposed along strike for only 1,500 feet, it may be a lens. The breccia is a gray limonite-stained rock and consists of numerous small angular fragments of phyllite and quartzite in a calcite matrix. Small brown grains of biotite are found scattered throughout the rock, and fine black graphite dust is found in some places.

PHYLLITE

Phyllite makes up the greater part of the metamorphosed sedimentary rocks found east of the phyllitic quartzite and north of the West Fork of the Sanpoil River and along both sides of Gold Creek between the junction of this creek with Deerhorn and King Creeks. This unit also extends northward into the Wauconda quadrangle.

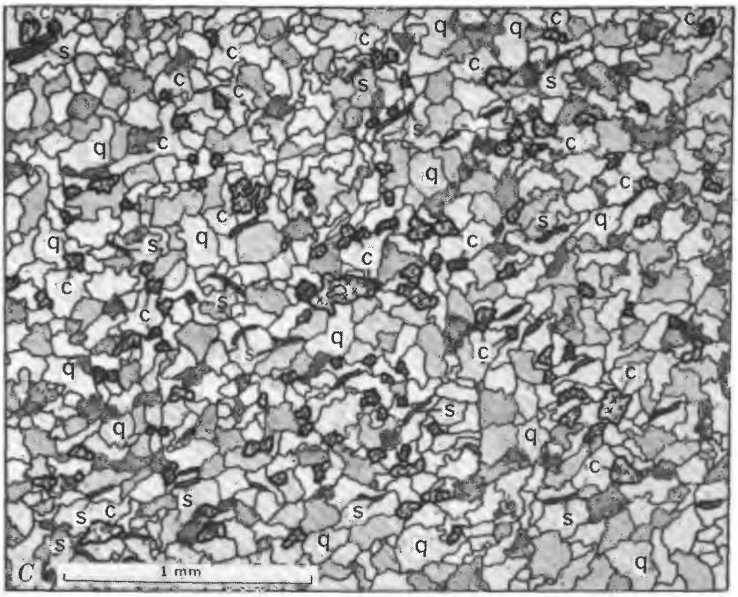
The phyllite is highly folded into many southward-plunging folds in the northern part of this area and into one large and several small



A. Hornblende-quartz-biotite schist from upper part of the phyllitic quartzite unit. Specimen collected from ridge near northern border of the Bald Knob quadrangle in SW¼ sec. 30, T. 35 N., R. 32 E. Large porphyroblasts of younger hornblende (h) cut across schistosity preserved by biotite (b) and ilmenite (i). Another distinctive mineral is calcite (c). Inclusions of ilmenite and quartz (q) occur in the hornblende. Matrix (m) is chiefly quartz but contains a little plagioclase and chlorite.

B. Graywacke from ridge north of Anderson Creek in the SW¼ sec. 32, T. 34 N., R. 32 E. An unsorted aggregate of angular to subrounded grains of quartz (q) and some plagioclase (p) in a fine-grained matrix consisting of sericite and chlorite (sc) and tiny

FIGURE 2.—MICRODRAWINGS OF THE METAMORPHOSED



grains of quartz. Trains of dark material cutting matrix consist of clay (cy) surrounded by limonite-stained matrix; these follow shears.

C. Quartzite from southwest side of North Star Creek in the SW¼ sec. 6, T 32 N., R. 31 E. Rock consists of sutured quartz grains (q) and accessory calcite (c) and sericite (s). Most of the quartzite in this unit contains less calcite than shown in this microdrawing. Crossed nicols.

D. Greenstone from ridge north of Deerhorn Creek in the SE¼ sec. 11, T. 34 N., R. 31 E. Rock made up chiefly of hornblende (h) and plagioclase (p) but also contains a little quartz (q) and ilmenite (i).

SEDIMENTARY ROCKS AND GREENSTONE

northward-plunging folds in the southern part. This unit is underlain by phyllitic quartzite and overlain, apparently conformably, by graywacke. The upper contact, however, is nowhere exposed.

The phyllite is a light silvery-gray to dark-gray fissile rock made up chiefly of quartz, sericite, and chlorite in varying proportions. A little plagioclase is generally present. Minor accessory minerals found in a few specimens of phyllite include biotite, limonite, graphite, zoisite, tourmaline, sphene, and pseudochiastolite. Pseudochiastolite was found in only one area, but it is one of the most interesting accessory minerals. Actually it is not a single mineral but consists of an intergrowth of sericite and a little untwinned feldspar that has formed pseudomorphically after chiastolite. Because chiastolite forms at high temperatures, the presence of pseudochiastolite suggests that the phyllite in which it is found was formed near the batholith. The change of chiastolite to sericite and feldspar indicates later retrograde metamorphism.

In most places the phyllite is fine grained, but in a few places the grain size is large enough so the rock might be called a schist. The phyllite was altered by contact metamorphism near its contact with the Colville batholith along Gold Creek. Here, the phyllite is more massive and in places was changed to a hornfels. The water content of the rock was increased, as is indicated by a few percent of large unoriented muscovite porphyroblasts and a generally greater sericite content. A little zoisite may also be present.

This rock also has some beds of quartzite, a few thin beds of graywacke, and one lens of impure limestone. Quartzite beds are commonly lenslike and may either pinch out or split within a short distance. Two types of quartzite were found: a fairly pure quartzite north of the West Fork of the Sanpoil River, and a micaceous quartzite along Gold Creek. In both areas the quartz grains are poorly sorted and conspicuously sutured. The quartzite north of the West Fork of the Sanpoil River is a light-gray fine-grained rock that may contain as much as 3 percent sericite. The quartzite adjacent to Gold Creek contains about 10 percent mica (sericite and chlorite) and generally a small percentage of hematite and calcite.

A small lens of fine-grained and laminated impure limestone crops out in the phyllite on a hillside just south of a metadiorite intrusive along the northern border of the quadrangle. One specimen was estimated to contain 82 percent calcite, 8 percent biotite, 7 percent graphite, and 3 percent quartz. Black tremolite crystals, as much as 1 inch long, occur in the limestone near its contact with the metadiorite.

GRAYWACKE

Graywacke occurs in two principal areas: an outcrop band, 4 miles by 1 mile, between the King Creek and Long Lake faults north of Strawberry Creek; and a discontinuous outcrop band, about 4 miles by ½ mile, west of the Sanpoil Volcanics north of Anderson Creek (pl. 1). The graywacke in the western outcrop band trends north and has an almost vertical dip, except where a small drag fold is present adjacent to the King Creek fault. In the eastern outcrop band the graywacke appears to be folded in several places, although the poor exposures make the structural features difficult to determine. The graywacke unit is at least 7,000 feet thick north of King Creek, as measured from the map.

The upper part of the graywacke unit contains considerable amounts of interbedded phyllite identical in lithology with that found in the underlying rock unit. In addition, a few small quartzite beds, one 2-foot bed of graywacke breccia, several small calcareous tuff beds, and a small limestone lens are found in this rock unit.

Crystal and rock fragments ranging from 0.02 to 5.0 mm in diameter compose 40–70 percent of the graywacke and occur in a very fine grained matrix of quartz, chlorite, sericite, and a little feldspar. Rock fragments rarely exceed 5 percent of the total and consist of pieces of quartzite, chert, and greenstone; crystal fragments are angular to subrounded and consist chiefly of quartz (fig. 2*B*). A small percentage of plagioclase is generally present as fragments, and in a few places orthoclase or microcline fragments make up as much as 25 percent of the rock. Calcite, zircon, magnetite, tourmaline, biotite, and hornblende are found in some specimens in amounts not exceeding 1 percent. The graywacke has generally a crude foliation (fig. 2*B*).

A bed of graywacke breccia is exposed on the nose of a fold on the east side of Gold Greek in the central part of sec. 17, T. 34 N., R. 32 E. This bed is interbedded with graywacke and consists of angular fragments of graywacke as much as 1 foot in diameter and some phyllite and a little vein quartz in a fine-grained graywacke matrix.

ROCKS IN THE CENTRAL PART OF THE QUADRANGLE

BLACK SHALE UNIT NO. 1

The metamorphosed sedimentary rocks discussed in this section are those found within T. 33 N. east of the Long Lake fault (pl. 1). Only one unit, black shale unit No. 1, occurs in this area. Scattered outcrops of black shale are found throughout an area 6 miles (east-west) by 2½ miles (north-south) in the center of the quadrangle (pl.1). These outcrops have been intruded by and overlie the granitic rocks of the

Colville batholith of Cretaceous age; they are overlain unconformably by the O'Brien Creek Formation and Sanpoil Volcanics of Tertiary age. The black shale is complexly folded, the folding having occurred both previous to and during the intrusion of the batholith.

This unit is made up chiefly of black shale and some intercalated dark-hematitic-red ledge-forming siltstone beds. In several places north of Central Peak, small limestone beds were found in the shale unit. The largest of these, occurring half a mile north-northwest of Central Peak, is about 100 feet wide and is exposed for 800 feet along strike.

The shale is a black well-laminated rock. The different laminae vary in grain size but all are very fine grained. Grain size is too fine to allow identification of many of the minerals, even in thin section. The principal mineral, however, is quartz; chlorite, sericite, and carbonaceous material are plentiful. Adjacent to the batholith the shale is partially recrystallized and, so, has a larger grain size; also, chlorite and sericite are more abundant, and biotite is commonly present. In places the recrystallized rock can be classified as a schist. Siltstone beds differ from the shale in that they are coarser grained, are hematitic red instead of black, form more prominent outcrops, and are massive instead of laminated.

ROCKS IN THE SOUTHWESTERN PART OF THE QUADRANGLE

The metamorphosed sedimentary rocks exposed in the southwestern part of the quadrangle occur for the most part west of the King Creek and Long Lake faults in Tps. 32 and 33 N. A small fault block of limestone, however, is found half a mile east of the Long Lake fault in the southwestern corner of the quadrangle, and several small inliers of quartzite occur in the Sanpoil Volcanics southeast of Little Owhi Lake. The rocks in this area are divided into three stratigraphic units: schist, black shale unit No. 2, and quartzite.

MICA-QUARTZ SCHIST

Schist is found in scattered areas 1–2½ miles southwest of Gold Lake and in several places along the western border of the quadrangle south of North Star Creek. This unit also extends at least 1½ miles west into the adjacent quadrangle. In the southern area the schist is overlain conformably to the southeast by black shale unit No. 2; to the north, west, and south it is cut off by the Colville batholith.

The mica-quartz schist is light to dark gray, well laminated and generally stained with limonite. Grain size commonly differs in adjacent laminae, ranging from about 0.04 to 0.8 mm in diameter. This rock varies in composition from a mica-rich to a quartz-rich schist. Most of the specimens contain, in addition to quartz, one or more of the following micaceous minerals: sericite, chlorite, and biotite. The most common is sericite, but in a few rocks chlorite is most common. Quartz occurs in subangular anhedral grains having sutured edges. Andalusite makes up as much as 10 percent of the schist on the west side of Parmenter Creek. Minerals found in a few places in amounts less than 1 percent include: tourmaline, pyrite, zircon, apatite, garnet, magnetite, hematite, sphene, and epidote.

The mica-quartz schist contains many interbeds of micaceous quartzite that range in thickness from less than ¼ inch to more than 100 feet. These beds are more resistant to weathering than the beds of mica-quartz schist and commonly form prominent ledges that extend generally only a few hundred yards.

BLACK SHALE UNIT NO. 2

Black shale unit No. 2 forms two northeast-trending outcrop bands about 2 miles long between Stepstone and Parmenter Creeks. The first band is located southeast of the outcrop of mica-quartz schist, and the second is found in a fault block between the Long Lake fault and a fault to the northwest along which a serpentine body has been intruded (pl. 1). This shale unit conformably overlies the schist unit and is overlain by the quartzite, discussed on page F16. The shale is in fault contact with the quartzite; hence, the true thickness of each unit is not known. The black shale unit No. 2, however, has a minimum thickness of 2,300 feet. A prominent layer of gray limestone, about 450 feet thick, is found about 500 feet above the base of the shale.

The black shale is a very fine grained well-laminated rock containing grains about 0.005 mm in diameter. The principal mineral is quartz; sericite and chlorite are also abundant. Carbonaceous matter may make up as much as 35 percent of the rock and is more abundant than in black shale unit No. 1. The shale is silicified over the greater part of the northern outcrop band between North Star and Parmenter Creeks. The silicified rock consists mainly of small angular quartz grains and as much as 15 percent sericite. In both thin section and hand specimen, it closely resembles the overlying fine-grained quartzite but differs in that it is commonly fractured, and contains numerous partings of sericite, plentiful small quartz veins, and—in a few places—unreplaced fragments of black shale. The limestone layer generally forms a prominent outcrop. Quartz is the chief impurity in the limestone and occurs in amounts generally less than 1 percent, but it may make up as much as 20 percent of small individual beds. Tremolite is found locally. Limestone in the outcrop band adjacent to the Long Lake fault is commonly brecciated and in several places has been altered to a brown dolomite. Fossils were found in the brecciated limestone in the NW¼ sec. 7, T. 32 N., R. 31 E. Although they were too poorly preserved to be identified specifically, they appeared to J. T. Dutro, Jr. (written communication, 1961) to be probably fragments of pelecypods, gastropods, and echinoderms. A fine-grained sandstone bed was noted in this unit in the NW cor. sec. 18, T. 32 N., R. 31 E. This rock differs from the shale in being more massive and brownish gray instead of black and in having a larger average grain size (0.05 mm in diameter).

QUARTZITE

The quartzite occurs mainly in a northeast-trending outcrop band about 0.7 mile by 3.5 miles between North Star Creek and the southwest corner of the quadrangle. The quartzite is in fault contact with the other metamorphosed sedimentary rocks and is intruded by small bodies of quartz monzonite, Scatter Creek Rhyodacite, and serpentine. In addition, nine small islands of quartzite project through the Sanpoil Volcanics southwest of Little Owhi Lake.

The quartzite is white, light gray, medium gray, tan, or light brown; it is well cemented, and the grains range from 0.04 to 0.3 mm in diameter. Beds range in thickness generally from ¼ inch to 20 feet. The quartzite consists chiefly of a mosaic of recrystallized quartz grains, which are commonly sutured (fig. 2*C*). A small percentage of micaceous minerals is present in most specimens; sericite is most common (fig. 2*C*), but in some places chlorite and biotite are present. Irregular grains of carbonate are found scattered through many specimens (fig. 2*C*), and less than 1 percent of zircon, magnetite, hematite, and sphene is found in some specimens.

Although this unit is composed predominantly of fine-grained quartzite, interbeds of phyllite and quartz-mica schist are locally present. The phyllite and schist are similar in mineralogy to the quartzite but contain more mica—generally biotite—and less quartz. In one occurrence of the schist a little zoisite was found. Phyllite is most common just above the exposed base of the unit.

The small bodies of quartzite southwest of Little Owhi Lake have been metamorphosed by the surrounding Sanpoil Volcanics. The quartzites were originally calcareous or dolomitic, but they are now tremolitic quartzite. They closely resemble the quartzite found adjacent to North Star Creek, but in some places they originally contained larger amounts of carbonate. Hence, these two areas of quartzite may possibly belong to different rock units.

METAMORPHOSED IGNEOUS ROCKS

The metamorphosed igneous rocks occur in the same general part of the Bald Knob quadrangle as the metamorphosed sedimentary rocks. They occupy a much smaller area and are distinguished from younger igneous rocks by a well-defined foliation. The metamorphosed igneous rocks found in this quadrangle are greenstone, which is extrusive, and granodiorite porphyry and metadiorite, which are intruded into the metamorphosed sedimentary rocks.

GREENSTONE

Greenstone is found only in the northern part of the Bald Knob quadrangle (pl. 1), where it forms a north-northwest-trending layer 3½ miles long by as much as 4,000 feet wide that occurs west of the West Fork of the Sanpoil River. It apparently conformably underlies the phyllitic quartzite on the east and has been intruded by the batholithic rocks on the west.

The greenstone is dark green and generally finely crystalline. In some places it is coarse grained and contains crystals as large as 0.5 by 1.5 mm; the finer grained variety apparently recrystallized into the coarser grained variety because it was heated by the adjacent batholith.

This rock was originally a flow probably of andesitic composition, and in a few places well-formed pillow structures are still preserved. Its present mineralogy and texture are different from the typical greenstone, as it has been changed by contact metamorphism with the batholith.

The greenstone (fig. 2*D*) is made up chiefly of hornblende (40–85 percent) and plagioclase (15–55 percent). Quartz (1–4 percent) occurred in all specimens examined, and sphene and ilmenite were commonly present, making up as much as 3 percent of the rock. Apatite, orthoclase, biotite, chlorite, augite, and calcite occurred in minor amounts in a few specimens.

Hornblende occurs in very pale green to green subhedral to euhedral crystals (fig. 2*D*). The plagioclase is found as anhedral crystals interstitial to those of hornblende. Zoning was not seen in any of the plagioclase crystals, and a large part of the plagioclase is untwinned. Most of the plagioclase ranges from An_{40} to An_{55}.

METADIORITE

Metadiorite forms small intrusives that cut the metamorphosed sedimentary rocks in the northern part of the quadrangle, west of Central Peak in the central area, and along North Star Creek in the southwestern area. The crosscutting is best exposed adjacent to the metadiorite intrusive that crosses North Star Creek in the southwestern part of the quadrangle. The intrusives range in size from a dike a few feet wide to the irregular-shaped body along North Star Creek that is 2,400 feet by 6,700 feet. The metadiorite intrudes and is therefore younger than the metamorphosed sedimentary rocks. It is older than the batholithic rocks, which in turn intrude the metadiorite along King Creek (secs. 23 and 26, T. 34 N., R. 31 E.), at a locality 1 mile northeast of Central Peak (secs. 6 and 7, T. 33 N., R. 32 E.), and on the northeast side of North Star Creek (secs. 25 and 36, T. 33 N., R. 30 E.).

The metadiorite was originally a diorite, which probably consisted chiefly of plagioclase and hornblende. Since it was formed, all of it has gone through one period of metamorphism, and some of it has gone through two periods. The first period of metamorphism was regional and low grade, and altered the adjacent clastic sedimentary rocks into rocks belonging to the green-schist facies. Because rocks of this facies are in equilibrium at low pressures and temperatures, the diorites, which formed at high temperatures, underwent retrograde metamorphism. None of the diorites reached the equilibrium of the green schist facies, probably owing to the slow rate of reaction between minerals at low temperatures and pressures, but some specimens of the metadiorite are closer to equilibrium than are others. The second period of metamorphism was due to the intrusion of the Colville batholith, which affected only the metadiorite adjacent to the intrusion. As a result of these two kinds of metamorphism, the modes and textures of metadiorite from different areas may vary considerably (table 1 and fig. 3 *A*, *B*, and *C*).

TABLE 1.—*Modes, in volume percent, of metadiorite*

[Tr, trace]

Mineral	Sample No. MHS—				
	58-57	75-57	78-57	143-57	107-58
Plagioclase	24	35	35	22	7
Quartz	3	2			
Calcite	10	4	.1	3	
Hornblende		49	15	29	88
Chlorite	53	3	23	19	2
Biotite		4	2	.5	
Pyroxene					.4
Clinozoisite			20		
Epidote				20	
Sericite					2
Sphene		.6	5		.6
Leucoxene	10		Tr	6	
Ilmenite				.9	.1
Magnetite		2	.3		
Apatite		.4			.3
Pyrite					Tr

58-57. Coarse-grained slightly foliated metadiorite from the north side of the West Fork of the Sanpoil River in the NE¼SW¼ sec. 6, T. 34 N., R. 32 E.

75-57. Coarse-grained nonfoliated metadiorite from 0.8 mile west-northwest of Long Lake.

78-57. Coarse-grained slightly foliated metadiorite from top of ridge west of Lime Creek on SE¼NE¼ sec. 31, T. 35 N., R. 32 E.

143-57. Fine-grained slightly foliated metadiorite from east side of Gold Creek in SW¼ sec. 19, T. 34 N., R. 32 E.

107-58. Coarse-grained nonfoliated metadiorite from ridge top north of North Star Creek in the SW¼ sec. 25, T. 33 N., R. 30 E., that has been contact metamorphosed by quartz monzonite.

The dark-green metadiorite may be either coarse grained and equigranular or fine grained to medium grained and schistose. In some outcrops it grades from a massive into a schistose texture. Most of the metadiorite intrusives consist of plagioclase, a principal mafic mineral that is either hornblende or chlorite, and in some specimens, important amounts of clinozoisite (fig. 3*B*) and epidote (fig. 3*C*). Andesine plagioclase (An_{33}–An_{44}, average about An_{38}) forms anhedral to subhedral crystals that are interstitial to the hornblende. Hornblende is pale green and forms anhedral to euhedral crystals, which are commonly partly altered to chlorite (fig. 3*B* and *C*). Hornblende is more common in rocks close to the batholith. The metadiorites are notable for their high titanium content, which is present in sphene (fig. 3*B*), leucoxene, or ilmenite (fig. 3*C*). Titanium is probably also present in some of the hornblende because small anhedral sphene crystals commonly occur in partly altered hornblende. Small anhedral grains of quartz, making up as much as 5 percent of the rock, were seen in about half the thin sections. Calcite in irregular-shaped grains is present in many specimens of metadiorite and is most abundant where the rock is low in hornblende and high in chlorite. Minor amounts of biotite, magnetite, and sericite were found in some specimens.

The metadiorite has been altered in a few places by fluids containing elements such as potassium and sulfur derived from the batholith. A hornblende-rich metadiorite adjacent to the batholith and to small dikes extending from the batholith along the ridge north of North Star Creek has been altered, by the addition of potassium, from a rock containing only a small percentage of biotite to a rock containing 15–70 percent biotite. Metadiorite dikes on a mountain 1½ miles west-southwest of Central Peak have been hydrothermally altered by fluids rising from the underlying batholith. Pseudomorphs of large crystals are common and indicate that these dikes were originally coarse grained, although the dikes now consist of masses of small crystals made up chiefly of chlorite and a pale-green amphibole, probably actinolite. Biotite, zoisite, and (or) calcite are also common in some specimens. Plagioclase makes up generally less than 1 percent of these dikes, as it has been almost entirely replaced by biotite and actinolite. Pyrite and pyrrhotite in small amounts are found disseminated in most dikes. The presence of these sulfides and the occurrence of a pyrrhotite-rich zinc lode on the Iron Dike claim (fig. 9) in one of these dikes (Pardee, 1918, p. 97) suggest that the fluids that altered the dikes may have come from the same source as those that formed the mineral deposits in the area.

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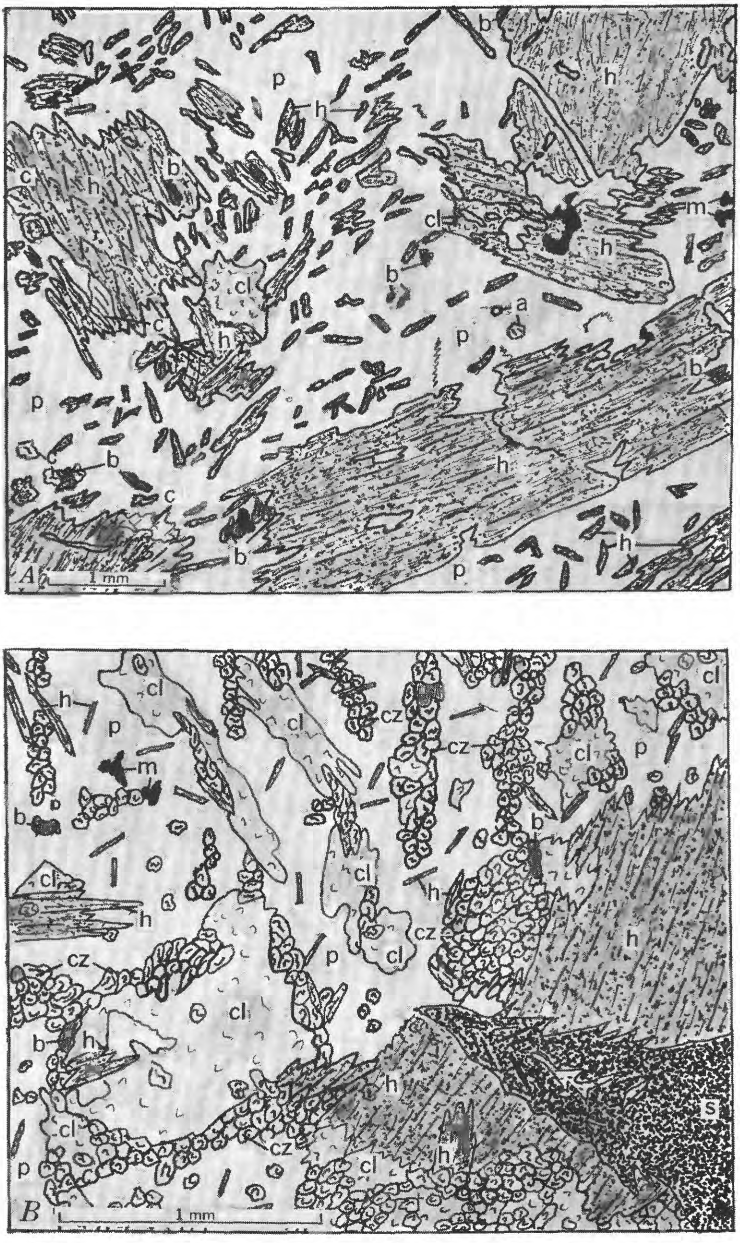
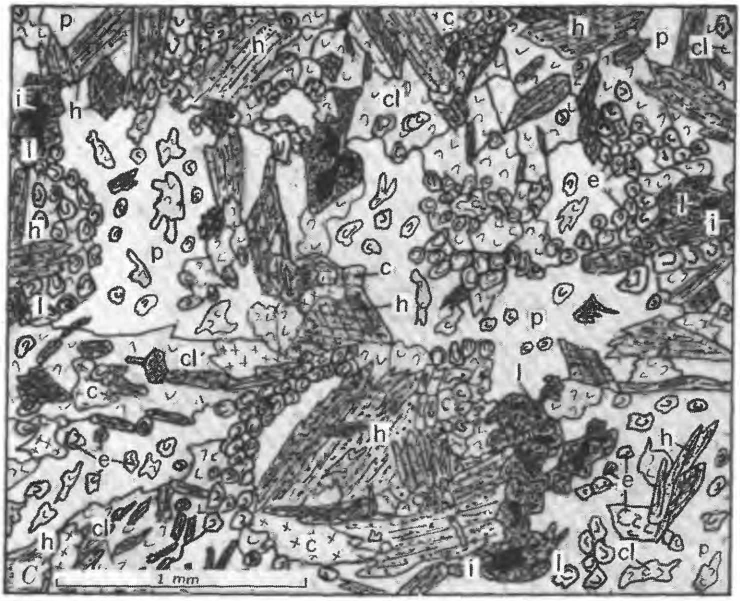
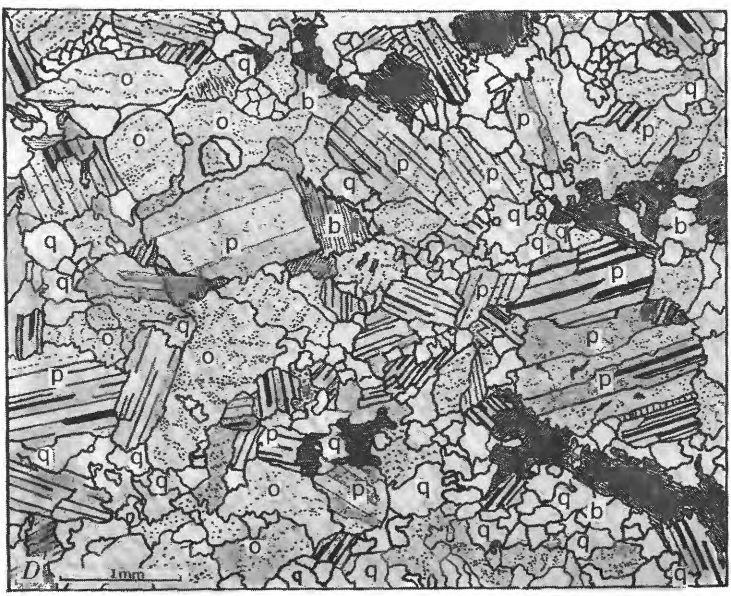


A. Metadiorite from intrusive 0.8 mile west-northwest of Long Lake. Rock consists chiefly of hornblende (h), as large porphyroblasts and many smaller crystals, and plagioclase (p). Other minerals shown are apatite (a), biotite (b), calcite (c), chlorite (cl), and magnetite (m). This drawing represents a part of the thin section from which the mode of specimen MHS-75-57 was made (table 1).

B. Metadiorite from top of ridge west of Lime Creek in the SE¼NE¼ sec. 31, T. 35 N., R. 32 E. Rock consists chiefly of plagioclase (p), hornblende (h), chlorite (cl), and clinozoisite (cz). Also shown is one large crystal of sphene (s) and a little biotite (b) and magnetite (m). This drawing represents a part of the thin section from which the mode of specimen MHS-78-57 was made (table 1).

FIGURE 3.—MICRODRAWINGS OF





C. Metadiorite from east side of Gold Creek in the SW¼ sec. 19, T. 34 N., R. 32 E. Rock consists chiefly of plagioclase (p), hornblende (h), chlorite (cl), and epidote (e). Leucoxene (l) was formed from ilmenite (i) and surrounds small remnants of this mineral. Other mineral shown is calcite (c). This drawing represents a part of the thin section from which the mode of specimen MHS-143-57 was made (table 1).

D. Quartz monzonite from ridge 200 yards east of Stepstone Creek in the SW¼ sec. 30, T. 33 N., R. 31 E. Bulk of rock consists of subhedral crystals of plagioclase (p), large anhedral ones of kaolinized orthoclase (o), and smaller ones of sutured quartz (q). Dark constituent is biotite (b). Crossed nicols.

METADIORITE AND QUARTZ MONZONITE

The chemical composition of the metadiorite is similar to that of the greenstone, and the metadiorite is probably the intrusive equivalent of the greenstone. Some specimens of metadiorite are identical in hand specimen with the greenstone and contain a similar suite of minerals in similar proportions. Much of the metadiorite, however, contains mafic minerals—epidote, chlorite, and clinozoisite—that are in equilibrium at relatively low temperatures. (Compare fig. 2*D* with figs. 3*A*, *B*, and *C*.) The greenstone, on the other hand, contains in excess of 1 percent only those mafic minerals—hornblende, sphene, and ilmenite—that are in equilibrium at relatively high temperatures. The mineralogic differences between the two rocks is probably due to differences in the kind and amount of metamorphism. Both rocks underwent low-grade regional metamorphism, and in addition all the greenstone and part of the metadiorite were contact metamorphosed at a higher temperature by the batholith. Thus, the mineralogy of the greenstone is similar only to the mineralogy of the metadiorite that underwent the second and higher temperature metamorphism.

GRANODIORITE PORPHYRY

Granodiorite porphyry is found only on the mountain about 1½ miles southwest of Gold Lake (pl. 1). This rock forms a large east-trending dike 2,500 feet by about 350 feet; it also forms a smaller dike about 400 feet by 250 feet, 450 feet east of the first dike.

The granodiorite porphyry dikes are intruded into quartz-mica schist and are cut by several dikes of Scatter Creek Rhyodacite of Teritiary age. The granodiorite porphyry has a crude foliation, which strikes across the dike and parallels that formed in the quartz-mica schist.

The granodiorite porphyry is light gray and is characterized by numerous white euhedral andesine phenocrysts, which make up 30–45 percent of the rock. These phenocrysts average 4 by 3 mm, are composed roughly of An_{37}, and contain numerous small orthoclase, muscovite, and quartz inclusions. The rock also contains about 5 percent quartz phenocrysts, which are only about one-eighth as large as those of andesine and are in general inconspicuous in hand specimen. The groundmass is made up of untwinned plagioclase, quartz, potassium feldspar, and mafic minerals. The average composition of the entire rock is estimated to be 62 percent plagioclase, 20 percent quartz, 8 percent orthoclase and microcline, 7 percent chlorite, 2 percent biotite, and less than 1 percent magnetite, apatite, epidote, leucoxene, muscovite, garnet, zircon, and pyrite. Much of the orthoclase occurs in tiny grains ringing plagioclase phenocrysts or in veinlets, suggesting a secondary origin for at least part of the potassium feldspar. The chlorite is formed by alteration of the biotite; the alinement of these two minerals gives the rock its foliation.

The texture of the granodiorite porphyry, the numerous inclusions in the large plagioclase crystals, and the late secondary origin of at least part of the orthoclase suggest that this dike was formed by replacement of the quartz-mica schist.

DIORITE

Diorite is found in two places in the Bald Knob quadrangle: along the upper part of the creek that lies to the east of Stepstone Creek and in the extreme southeast corner of the quardrangle (pl. 1). In the first locality the diorite forms an irregular triangular-shaped body, 2 miles (north-south) by a maximum of 1½ miles (east-west); in the second locality it occupies a triangular-shaped area of half a square mile that is but a small part of a larger diorite body lying mainly in the three adjacent quadrangles.

The diorite is younger than the metamorphosed sedimentary rocks, as it cuts the mica-quartz schist, contains inclusions of phyllite, and has not been metamorphosed. The lack of any signs of metamorphism, such as well-defined foliation and an alteration of plagioclase to sericite and chlorite, also indicates that the diorite is younger than the metadiorite and greenstone. The diorite is older than the batholithic rocks, which vein the diorite as well as contain inclusion of the diorite. The diorite is also cut by dikes of Scatter Creek Rhyodacite of Tertiary age.

The diorite varies considerably in grain size, color, and composition. Most of this rock is fairly equigranular, and most grains range in size from about 0.25 mm by 0.45 mm to 1.5 mm by 3.0 mm. Some diorite in the southeastern part of the quadrangle, however, is porphyritic and has an aphanitic matrix in which the grain size is about 0.02 mm and phenocrysts similar in size to crystals in nonporphyritic diorite occur. The color varies with the amount of mafic minerals present and ranges from a very light gray to a dark gray.

The composition varies most in the proportion of felsic to mafic minerals. The principal felsic mineral, plagioclase, makes up 40–85 percent of the rock. It generally forms subhedral crystals, commonly zoned, that range from An_{40} to An_{57}. Small anhedral quartz grains are in most, but not all, specimens in amounts that range generally from 3 to 5 percent. Quartz composes 9 and 15 percent of the rock in two specimens that were collected adjacent to the contact of the diorite with the Colville batholith; because of the high quartz content, the two specimens would be classified as quartz diorite (Grout, 1932,

p. 50). Some of the quartz in these two specimens, however, may have been introduced during the intrusion of the batholith. Orthoclase is rarely present, although in one specimen collected adjacent to the batholith it made up as much as 6 percent of the rock.

The principal mafic minerals are hornblende and chlorite, which make up 5–52 percent of the rock. These minerals occur largely as anhedral crystals; however, where the rock is porphyritic, they commonly occur as euhedral crystals. The chlorite was formed by deuteric alteration of either hornblende or biotite. Sphene, ilmenite, and apatite are present in most specimens of diorite; they may make up as much as 2 percent of the rock but generally compose less than 1 percent. Minerals found in minor amounts in a few specimens include calcite, magnetite, epidote, zircon, pyrite, hematite, clinozoisite, muscovite, and tourmaline. Modes were determined for three specimens of diorite, and the variation between them is indicated on table 2.

TABLE 2.—*Modes, in volume percent, of diorite*

[Tr, trace]

Mineral	Sample No. MHS—		
	21–58	77–58	92a–58
Plagioclase	46	40	43
Orthoclase		3	6
Quartz		5	9
Hornblende	31	28	17
Biotite		21	22
Chlorite	20	1.4	1.6
Sphene	.3	1.6	1.1
Ilmenite	1.3	.2	.08
Apatite	.5	Tr	Tr
Clinozoisite	.7		
Pyrite	Tr		Tr
Calcite			Tr
Epidote		Tr	
Zircon		Tr	

21–58. Diorite from small ridge on the east side of a creek to the east of Stepstone Creek in the central part of sec. 20, T. 33 N., R. 31 E.
77–58. Diorite from ridge east of Stepstone Creek in S½ sec. 19, T. 33 N., R. 31 E.
92a–58. Quartz diorite adjacent to Colville batholith from ridge east of Stepstone Creek near northern border of sec. 32, T. 33 N., R. 31 E.

COLVILLE BATHOLITH

NAME, AGE, AND DISTRIBUTION

The name "Colville batholith" was given by Pardee (1918, p. 30) to the large body of granitic rocks that underlies more than half the Colville Indian Reservation (fig. 1); Pardee (1918, p. 33–34) considered the rocks to be probably of Mesozoic age. More recent mapping to the north of the reservation by Muessig and Quinlan (1959) in the Republic quadrangle and by Calkins, Parker, and Disbrow (1959) in the Curlew quadrangle indicates that some of the granitic rocks are of Tertiary age. In these two quadrangles the O'Brien Creek Formation of Eocene(?) age locally contains beds of boulder conglomerates. Some of the beds in the northeastern part of the Republic quadrangle contain boulders of quartz monzonite and granodiorite (S. J. Muessig, oral communication, 1958), indicating that these boulders were derived from intrusions older than the O'Brien Creek Formation. In another place, the O'Brien Creek Formation is overlain by the Sanpoil Volcanics, whose intrusive equivalent the Scatter Creek Rhyodacite, is cut by quartz monzonite bodies in the northeastern part of the Republic quadrangle (Muessig, oral communication, 1958) and the east-central part of the Curlew quadrangle, (R. L. Parker, oral communication, 1960); this evidence indicates that some of the quartz monzonite is from intrusions younger than the O'Brien Creek Formation, and hence of Tertiary age. The quartz monzonites of the two ages are identical in hand specimen (Muessig, oral communication, 1958), and thus the igneous rocks in the reservation mapped by Pardee (1918, pl. 1) as part of the Colville batholith may actually belong to two batholiths of different ages. The term Colville batholith is here reserved for the older rocks probably of Mesozoic (Cretaceous(?)) age.

Exposures are poor in the Bald Knob quadrangle, and no intrusion of older granitic rocks by younger was detected. In many places in the Bald Knob quadrangle, however, the batholithic rocks are intruded by dikes of Scatter Creek Rhyodacite of Tertiary age; this evidence indicates that the batholithic rocks in these areas are probably of Mesozoic age and are hence part of the Colville batholith as defined above. I am not suggesting, however, that the younger batholithic rocks are entirely absent in the Bald Knob quadrangle, but as no way was found to prove their presence, all the batholithic rocks are discussed as being probably Mesozoic.

Specimens of various batholithic rocks were collected in the Curlew, Republic, and Wauconda quadrangles by S. J. Muessig, R. L. Parker, and J. A. Calkins for zircon age determinations using the method of Larsen, Keevil, and Harrison (1952). The work was done by T. W. Stern (oral communication, 1960), who found such a small amount of original lead in the zircon from these rocks that a consistent age determination could not be made between two samples of the same specimen.

The areal extent of the batholithic rocks is not known, as only certain areas in this part of Washington have been mapped. Pardee

(1918, p. 30), however, estimated that within the Colville Indian Reservation batholithic rocks underlie not less than 1,700 square miles. The east edge of the batholithic rocks is along the east edge of the reservation, where these rocks are in contact with metamorphosed sedimentary rocks of the Covada Group. South of the Columbia River the batholithic rocks disappear under the Columbia River Basalt, although exposures of batholithic rocks are found in the Grand Coulee as far as 9 miles southwest of Coulee Dam and near Creston, which is about 9 miles east of Wilbur (fig. 1). The west edge of the Colville batholith has been mapped along the Okanogan Valley north of Omak almost to the Canadian border (Waters and Krauskopf, 1941, pl. 1), and granitic rocks have been mapped by Muessig and Quinlan (1959) in the Republic and Wauconda quadrangles and by Calkins, Parker, and Disbrow (1959) in the central and southern part of the Curlew quadrangle.

Rocks of the Colville batholith occupy a large irregular-shaped area in the northwestern part of the quadrangle. Near the central part of the quadrangle the batholith extends eastward to the headwaters of Anderson Creek along an old fault in the metamorphosed sedimentary rocks and under the Park City mining district, where it is exposed in the underground workings of several of the mines and in a separate body 1½ miles west-southwest of Central Peak. In addition, several smaller exposures of granitic rocks are found on the west side of Parmenter Creek in the southwest corner of the quadrangle and in a few small isolated outcrops surrounded by Sanpoil Volcanics along the southern border of the quadrangle. These small outcrops represent high points on the underlying granitic terrane.

RELATION TO OTHER ROCKS

The Colville batholith cuts and is hence younger than the greenstone, graywacke, phyllite, mica-quartz schist, black shale units No. 1 and No. 2, quartzite, metadiorite, and diorite. The batholith is unmetamorphosed and hence is younger than rocks that have been metamorphosed. The batholith is intruded by many dikes of Scatter Creek Rhyodacite and is overlain by the Sanpoil Volcanics.

DESCRIPTION

The Colville batholith is made up most commonly of fairly equigranular rocks. Most outcrops are light colored and characteristically rounded and can be thus recognized on the higher mountains from long distances. Grain sizes and textures vary widely. The average grain size of the rocks ranges from 1.5 to 9.5 mm in diameter; most rocks have an average grain size of about 6.5 mm. Large areas underlain by fine-grained rocks are found in secs. 30 and 31,

T. 33 N., R. 31 E., along Stepstone Creek; in secs. 25 and 36, T. 34 N., R. 31 E., adjacent to Gold Creek; and in sec. 1, T. 33 N., R. 30 E., and secs. 5 and 6, T. 33 N., R. 31 E. northwest of Gold Lake.

Quartz monzonite is the most common rock type (fig. 3*D*), quartz diorite is next in abundance, and granodiorite is scarce. The rocks tend to be coarser grained where potassium feldspar is abundant than where it is scarce or absent. Hence, in general the fine-grained rocks are quartz diorite; and the coarser grained ones, quartz monzonite.

Pardee (1918, p. 30) believed most of the rocks of the Colville batholith to be granite, although he noted the presence of granodiorite and quartz diorite in its marginal parts. In the Bald Knob quadrangle, however, I have not found any igneous rocks that contain a large proportion of potassium feldspar over plagioclase and that would therefore be called granite according to the classification used in this paper (Grout, 1932, p. 50).

The common minerals of the batholithic rocks are plagioclase orthoclase or microcline, quartz, and biotite (fig. 3*D*). Plagioclase (An_{25}–An_{42}, averaging about An_{34}) occurs in anhedral to subhedral crystals in which twinning is fairly common and zoning is scarce. Twinning indicates that the potassium feldspar is orthoclase in some specimens and microcline in others. The potassium feldspar crystallized both early and late during the cooling of the magma and in some places formed large euhedral phenocrysts and in other places smaller anhedral crystals along the contacts between the plagioclase and quartz crystals. The anhedral potassium feldspar is most common and is the only kind found in some rocks. Quartz occurs in anhedral crystals whose borders are generally sutured (fig. 3*D*). Biotite is the most abundant mafic mineral and is almost universally present in amounts ranging from less than 1 percent to as much as 20 percent; it is found as small brown irregular grains commonly along the border of larger feldspar and quartz grains. Hornblende is absent or scarce in most specimens, but specimens from two areas adjacent to the batholithic rocks contain more than 5 percent hornblende. Chlorite formed from biotite is found in some places. Magnetite, apatite, and sphene form less than 1 percent of most specimens. Other accessories that occur in minor amounts in some specimens are zircon, tourmaline, muscovite, garnet, and epidote. Modes were measured for the major minerals in eight specimens (table 3), which were first stained with sodium cobaltinitrite, using the method of Gabriel and Cox (1929), to make the identification of potassium feldspar easy. Modes on fine-grained specimens were measured on thin sections following the method of Chayes (1949). Those on coarse-

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grained specimens were measured on rock slabs following the method of Jackson and Ross (1956).

TABLE 3.—*Modes, in volume percent, of rocks from the Colville batholith*

[Tr, trace]

Mineral	Sample No. MHS–							
	136–57	147–57	181–57	183–57	92–58	120–57	50–58	106–58
Plagioclase	32	43	39	30	31	42	40	28
Orthoclase or microcline	24	12	23	35	33	33	35	47
Quartz	38	22	31	33	23	17	16	20
Biotite	5	16	7	2	--------	--------	--------	--------
Chlorite	--------	2	--------	--------	13	--------	--------	--------
Hornblende	--------	5	--------	--------	--------	--------	--------	--------
Magnetite	.3	Tr	.2	.4	.1	--------	--------	--------
Muscovite	Tr	--------	Tr	Tr	Tr	--------	--------	--------
Apatite	Tr	Tr	Tr	Tr	Tr	--------	--------	--------
Sphene	--------	Tr	--------	--------	--------	--------	--------	--------
Zircon	--------	Tr	Tr	--------	--------	--------	--------	--------
Mafic minerals (undifferentiated)	--------	--------	--------	--------	--------	8	9	5

136–57. Quartz monzonite from ridgetop 1½ miles southwest of Dugout Mountain.
147–57. Quartz diorite adjacent to batholith contact in the SE¼ sec. 25, T. 34 N., R. 31 E.
181–57. Quartz monzonite from Sixmile Spring on southeast slope of Strawberry Mountain.
183–57. Quartz monzonite from ridgetop at junction of secs. 35, 36, 1, and 2, Tps. 33 and 34 N., R. 30 E.
92–58. Quartz monzonite adjacent to diorite contact in NW¼ sec. 32, T. 33 N., R. 31 E.
120–57. Quartz monzonite from top of Dugout Mountain.
50–58. Quartz monzonite from ridge in NE¼ sec. 18, T. 33 N., R. 31 E.
106–58. Quartz monzonite from west edge of area in east-central part of sec. 23, T. 33 N., R. 30 E.

CHEMICAL COMPOSITION

Chemical analyses and norms (table 4) were made on two samples for which modes had previously been determined (table 3). The rocks composing these two samples were widely divergent in character; one was a fine-grained rock containing abundant mafic minerals and some potassium feldspar (sample MHS–147–57), and the other was a coarse-grained rock containing some mafic minerals and abundant potassium feldspar (sample MHS–181–57). As the mode of another specimen (MHS–183–57, table 3) contains even less mafic minerals and more potassium feldspar than either of the two analyzed specimens, the difference in chemical composition between extremes in this rock is larger than indicated by these two analyses. These analyses do indicate, however, that the rocks of the Colville batholith vary considerably in composition, although all would be classified as an intermediate type of granitic rock. Chemical analyses have also been made of three specimens of Scatter Creek Rhyodacite (table 6) and of three specimens of flows from the Sanpoil Volcanics (table 5). The values obtained in both the chemical analyses and norms for these six specimens are intermediate to those obtained for the two specimens from the Colville batholith (table 4). Hence, the magma that formed all three rocks came very possibly from the same source.

TABLE 4.—*Chemical analyses and normative compositions, in weight percent, of two specimens from the Colville batholith*

[Chemical analyses by J. W. Goldsmith]

	Sample No. MHS-	
	147-57	181-57
Chemical analyses		
SiO_2	61.13	72.29
Al_2O_3	16.73	15.17
Fe_2O_3	.80	.84
FeO	4.33	.54
MgO	2.63	.33
CaO	5.04	1.90
Na_2O	3.75	4.57
K_2O	2.38	3.40
H_2O-	.06	.07
H_2O+	1.16	.24
TiO_2	.73	.24
P_2O_5	.29	.07
MnO	.11	.04
CO_2	.52	.01
Total	99.66	99.71
Normative compositions		
Quartz	14.58	28.08
Orthoclase	14.46	20.02
Albite	31.96	38.77
Anorthite	19.74	9.45
Hypersthene	12.80	.80
Magnetite	1.16	.93
Ilmenite	1.37	.46
Hematite	----------	.16
Corundum	----------	.51
Apatite	.67	----------
Calcite	1.20	----------
Total	97.94	99.18

147-57. Quartz diorite adjacent to batholith contact in the SE¼ sec. 25, T. 34 N., R. 31 E. (See table 3.)
181-57. Quartz monzonite from Sixmile Spring on southeast slope of Strawberry Mountain. (See table 3.)

INTERNAL STRUCTURE AND BORDER RELATIONS

The greater part of the Colville batholith in the Bald Knob quadrangle consists of nonfoliated, nonlineated rocks. Foliation, where present, is most common near the edge of the batholith, and lineation is most common in the central part. Foliation is found adjacent to the eastern contact of the batholith with greenstone north of Deerhorn Creek and with mica-quartz schist in the NW¼ sec. 19, T. 33 N., R. 31 E., on the east side of Stepstone Creek. Here the rock is a mafic-rich quartz diorite that contains scattered inclusions of country rock. The foliation in these two areas generally strikes north or northwest and is in general parallel to the foliation in the adjacent country rock. In addition, in the NW¼ sec. 19 the contact between the country rock and the batholith is gradational. This foliation along the margins of the batholith is probably derived from the country rock, as is evidenced by its parallelism with the foliation of the metamorphosed sedimentary rocks, the presence of inclusions, and the gradational contact.

Foliated rocks occur also in a narrow zone adjacent to the King Creek fault between Deerhorn and King Creeks; this foliation is apparently parallel or subparallel to the adjacent fault and is probably cataclastic in origin. Foliation and lineation in other parts of the batholith may have formed by movement within the batholith after part of it had consolidated. Pronounced foliation of this type occurs 20 miles to the west-northwest along the valley of the Okanogan River and was described by Waters and Krauskopf (1941) in considerable detail. The batholith in the area described by Waters and Krauskopf consists of a structureless central mass that grades into a belt of foliated igneous rock, which commonly shows intricate swirling of foliation. These swirled rocks grade into a peripheral belt of variable but well-foliated migmatitic gneisses that are characterized by severe granulation of the constituent minerals. Over broad zones this rock is a mylonite; locally, recrystallization has produced rocks resembling metamorphic granulites. In comparison to such areas, the rocks of the Bald Knob quadrangle are nearly nonfoliated. Granulation is not visible in hand specimen, but under the microscope, pockets of granulated material are seen among larger nongranulated mineral grains in a few specimens. Granulation is common in the lineated rocks in the northwestern part of the Bald Knob quadrangle, and movement before consolidation may have been the cause of the lineation found in that part of the quadrangle.

The contact of the batholith and the country rock is in part concordant and in part discordant; in places it is a fault contact. The rocks of the batholith interfinger with greenstone in secs. 35 and 36, T. 35 N., R. 31 E., on the west side of the West Fork of the Sanpoil River and with the graywacke in sec. 25, T. 34 N., R. 31 E., on the east side of Gold Creek. Small dikes of granitic rocks are common in some places in the country rock within half a mile of the batholith contact. Two small pegmatites were seen in the batholith near its outer margin in the center part of sec. 11, T. 34 N., R. 31 E.

SERPENTINE

Serpentine forms small lenticular intrusives, most of which occur in a northeast-trending belt about 3.5 miles by 0.7 mile extending from

Parmenter Creek to the creek east of Stepstone Creek. A partially serpentinized dunite, too small to be shown on plate 1, was also seen in the NE¼ sec. 11, T. 34 N., R. 31 E., on a ridge about three quarters of a mile southwest of the West Fork of the Sanpoil River, and a small serpentine intrusive about 150 feet long is exposed through the Sanpoil Volcanics half a mile southeast of Little Owhi Lake. The bodies range in size from 20 feet by about 10 feet to 2 miles by a maximum of ¼ mile.

The age of the serpentine is not known, but this rock is intruded into black shale unit No. 2 and quartzite in the southwestern part of the quadrangle and into greenstone southwest of the West Fork of the Sanpoil River.

Pardee (1918, p. 29, pl. 7) noted that the serpentine is cut off by the Colville batholith just east of Stepstone Creek. The area where the two rock types presumably come in contact is occupied by a small alluvium-filled valley, and the band of serpentine mapped by Pardee is actually several separate bodies rather than one continuous unit. Hence, the evidence here as to the relative age of the serpentine to the Colville batholith is not conclusive. The serpentine, however, is older than at least some of the Tertiary Scatter Creek Rhyodacite, as the largest body of serpentine is intruded by several rhyodacite dikes.

The rocks described here under serpentine include not only true serpentine but also associated talc-magnesite rocks. Talc-magnesite rocks commonly make up a part of some of the intrusives containing true serpentine and were probably formed from serpentine by hydrothermal alteration (Hess, 1933, p. 636). Talc-magnesite rock is most common where the mafic bodies are adjacent to the large Long Lake fault. The greater part of the rock mapped as serpentine east of Stepstone Creek consists of talc-magnesite rock, and the only place east of Stepstone Creek where this serpentine is not converted to talc-magnesite rock is in the intrusive farthest from the fault. The largest serpentine body also consists of talc-magnesite rock in the area between North Star and Stepstone Creeks adjacent to the Long Lake fault.

The talc-magnesite rock is a light greenish-gray to gray slick-feeling rock containing numerous tan shiny magnesite crystals. On weathered surfaces the rock is generally light brown and has numerous pits where the magnesite has weathered out. The rock is made up of 55–75 percent talc, 25–40 percent magnesite, and less than 1 percent to as much as 5 percent magnetite.

The serpentine is generally dark greenish black, although in some places it has irregular tan blotches. It is composed chiefly of antigorite and lesser amounts of magnetite, chrysotile, anthophyllite, chlorite, and picotite (iron-chromium spinel). The picotite forms small islandlike segregations in the magnetite.

The small dunite body southwest of the West Fork of the Sanpoil River is black on a fresh surface and tan on a weathered one. It consists of about equal amounts of olivine and of antigorite, which veins the olivine in a networklike pattern. Minor amounts (2 percent or less) of chrysotile, chromite, magnetite, and pyrrhotite are also found. The presence of this partially serpentized dunite body at this locality, although separated from the other serpentines by at least 10.5 miles, suggests to me that the other serpentines may originally have also been dunites.

VOLCANIC AND RELATED ROCKS

Volcanic rocks underlie most of the southeastern half of the Bald Knob quadrangle (pl. 1). The volcanic and related rocks consist of rhyodacite and quartz latite flows, tuffs, breccias, dikes, and other small intrusive bodies. Flows make up by far the greatest bulk of these rocks. All the flows, tuffs, and breccias in this quadrangle lie within the Republic graben. This graben is bounded on the northwest by either the Long Lake or King Creek faults and on the southeast by the Sherman fault (pl. 1).

These rocks are divided into three formations: (1) the O'Brien Creek Formation of Eocene(?) age, a relatively thin basal unit composed chiefly of tuff and some breccia; (2) the Sanpoil Volcanics of Eocene or Oligocene age, a thick unit composed largely of flows but containing some interbedded tuffs; and (3) the Scatter Creek Rhyodacite of Eocene or Oligocene age, consisting of the dikes and other small intrusive bodies.

O'BRIEN CREEK FORMATION

The basal Tertiary formation in the Republic quadrangle (fig. 1) was named the O'Brien Creek Formation by Muessig (1962) for exposures found along the North Fork of O'Brien Creek. In the Republic quadrangle this formation consists of a thick series of tuffs and some conglomerate. Muessig (1962) placed its top at the base of the lowest flow in the overlying Sanpoil Volcanics and reported its thickness in the Republic and Wauconda quadrangles as between 1,350 and 6,000 feet.

In the northern and central parts of the Bald Knob quadrangle, a pyroclastic unit is exposed below the flows of the Sanpoil Volcanics. This unit is made up chiefly of tuffs, some of which are waterlaid, and in a few places of volcanic breccia. The name O'Brien Creek

Formation is used in this report for all the pyroclastic rocks lying below the lowest flow of the Sanpoil Volcanics.

The O'Brien Creek Formation is exposed in the northern part of the area on both sides of Gold Creek near its mouth; in the central part of the area it is exposed on the west end and also about 1 mile south of Castle Mountain. Where the base of the O'Brien Creek is exposed, it unconformably overlies graywacke in the northern part of the area and black shale in the central part.

Although the O'Brien Creek Formation is overlain conformably by flows of the Sanpoil Volcanics, the basal flow of the Sanpoil may be different from place to place. For example, on the south side of the West Fork of the Sanpoil River about three-quarters of a mile west of the mouth of Gold Creek, a pyroclastic unit consisting of a welded tuff and an underlying water-laid well-stratified tuff underlies the lowest flow (pl. 1). Half a mile northeast, on the north side of the West Fork of the Sanpoil, a pyroclastic unit consisting of a water-laid well-stratified tuff and an underlying volcanic breccia is found at the same elevation but is underlain by at least 100 feet of flow. It is not known whether the pyroclastic unit on the north side of the West Fork of the Sanpoil is younger than the one on the south side or whether the unit is the same age and the flow that underlies the pyroclastic unit on the north side of the river does not extend as far.

The O'Brien Creek Formation has a highly variable strike and dip. Dips of the beds range from a few degrees to 37° but in general are 10°–20° flatter than those of adjacent metamorphosed sedimentary rocks.

The greater part of the O'Brien Creek Formation in the Bald Knob quadrangle is air-laid tuff, but some is water laid.

Well-stratified water-laid tuff is found on the ridge west of the junction of Gold Creek with the West Fork of the Sanpoil River and along the road 1 mile west-southwest of Central Peak. The tuff at both localities unconformably overlies metamorphosed sedimentary rocks. At the first locality the water-laid tuff is overlain by air-laid tuff, but at the second locality it is overlain by flows of the Sanpoil Volcanics. The water-laid tuff is generally laminated by well-sorted fine- and coarse-grained material. Graded bedding is visible in some layers. The coarsest layers are found west of Central Peak, where they contain angular fragments of black shale one-quarter of an inch in diameter. These fragments may make up as much as 35 percent of the rock. Intercalated with some of these layers are layers of extremely fine grained tuff, but in these layers, fragments of black shale are much smaller and rarely make up more than a small percentage of the rock. Most of the finer grained tuff layers are crystal tuffs containing 30–50 percent crystal fragments and as much as 20 percent glass fragments. Plagioclase is by far the commonest mineral in the water-laid tuff, making up about 10–45 percent of the rock. Quartz (3–5 percent) is next in abundance, followed by biotite, chlorite, or hornblende. Apatite and magnetite are generally present in small amounts. The rest of the tuff is composed of ash that consists of a light-brown partly divitrified glass. Imprints of grass and small branches occur sparsely in one tuff layer that crops out west of the mouth of Gold Creek.

Air-laid tuff is found in all areas of the O'Brien Creek Formation shown on plate 1. Its exposed thickness ranges generally from 20 to 1,500 feet. Its contact with the overlying Sanpoil Volcanics is generally sharp but is gradational at the outcrop exposed along the east side of the road 2 miles west of Central Peak. In most places this rock is a welded tuff and contains fragments of the older metamorphosed sedimentary rocks, of rhyodacite, and in places of devitrified glass. Generally, the metamorphosed sedimentary-rock fragments found in the tuff are of the same type as those found in the underlying metamorphosed sedimentary rocks; some tuff layers, however, have no rock fragments (fig. 4*A*). Crystal fragments make up 20–65 percent of the tuff; three-quarters of the fragments in most specimens are andesine or labradorite. Other crystal fragments in general order of decreasing abundance are hornblende, biotite, quartz, orthoclase, magnetite, and sphene. Quartz varies most in abundance, ranging from a trace to 10 percent of the rock (fig. 4*A*). The matrix is a light-gray ash.

The tuffs of the O'Brien Creek Formation (fig. 4*A*) resemble some of the tuffs of the Sanpoil Volcanics. In general, however, fragments of metasedimentary rocks are more common in the O'Brien Creek Formation. No fossils other than the few fragmentary imprints of grass and branches in the tuff layer west of the mouth of Gold Creek have been found in the O'Brien Creek Formation in the Bald Knob quadrangle. In the northern part of the Republic quadrangle (fig. 1), however, Muessig (1962) found plant fossils in water-laid tuff along the road in the NW¼ sec. 9, T. 37 N., R. 33 E. R. W. Brown (written communication, 1958) of the U.S. Geological Survey, who identified these plants, said: "This material is not well preserved and consequently, question marks occur within tentative identifications. The aspect of the collection as a whole is like that of the Eocene of Alaska and of the Puget Group of Washington."

The O'Brien Creek Formation is roughly equivalent to the Kettle River Formation (Daly, 1912, p. 394–397; Little, 1957), which is exposed in British Columbia along the Kettle River west of Midway and was described by Little (1957) as "acidic tuff, and local basins of conglomerate and sandstone." North of Grand Forks in the Franklin mining district, British Columbia, Drysdale (1915, p. 64) reported that the Kettle River consists mostly of rhyolitic grits intercalated with rhyolite flows, tuff, and conglomerate. Drysdale (1915, p. 67–68) tentatively assigned the Kettle River in part to the Eocene and in part to the Oligocene. This assignment is based on a rather limited collection of plant fossils that were identified by D. P. Penhallow.

SANPOIL VOLCANICS

NAME AND DISTRIBUTION

The name Sanpoil Volcanics was given by Muessig (1962) to the thick sequence of volcanic rocks that conformably overlie the O'Brien Creek Formation of Eocene(?) age and unconformably underlie tuffs of Oligocene age in the Republic and Wauconda quadrangles. These volcanics form a continuous outcrop area extending northward into the Curlew quadrangle and southward into the Bald Knob and Seventeenmile Mountain quadrangles. The formation is named after the Sanpoil River, which is bounded for many miles by cliffs cut in this formation.

In the Bald Knob quadrangle the Sanpoil Volcanics includes all the rocks mapped by Pardee (1918, pl. 1) as andesite and much of those that he mapped as porphyry. Both rocks are of similar composition and of contemporaneous age. They differ according to Pardee (1918, p. 39) by the porphyry being the intrusive equivalent of the extrusive andesite. Many of the rocks he mapped as porphyry, however, are interbedded with tuff and are most likely flows; these rocks are included in the Sanpoil Volcanics.

The Sanpoil Volcanics covers the greater part of the southeastern half of the Bald Knob quadrangle (pl. 1). The entire formation lies southeast of either the King Creek or Long Lake faults and northwest of the Sherman fault. It is the most resistant to weathering of any formation in the quadrangle, so that large areas of bare rock are exposed on many mountain tops. Streams cutting through this unit are commonly bounded by steep valley walls; cliffs 1,200 feet high are cut into this formation southwest of West Fork and along the headwaters of the Nespelem River.

RELATION TO OTHER ROCKS

The Sanpoil Volcanics unconformably overlies the older metamorphosed sedimentary and batholithic rocks; it conformably overlies the O'Brien Creek Formation, which in some places has a gradational contact. As noted by Pardee (1918, p. 39), rocks now called the

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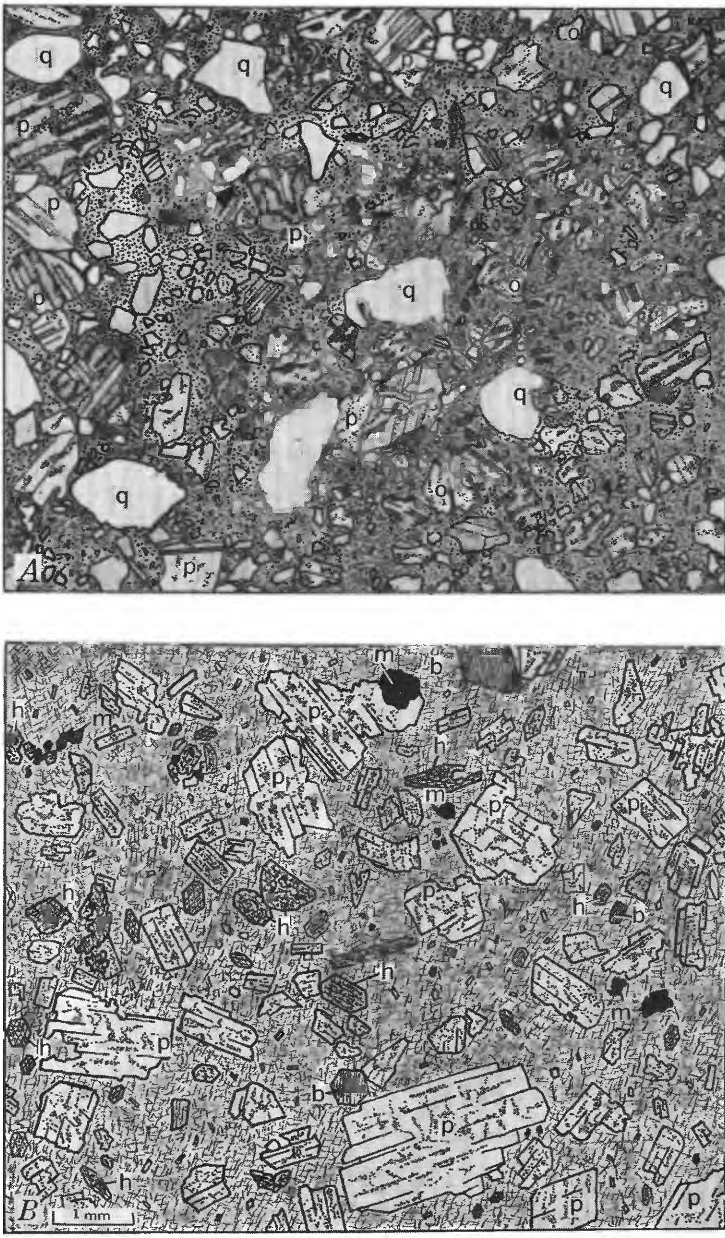
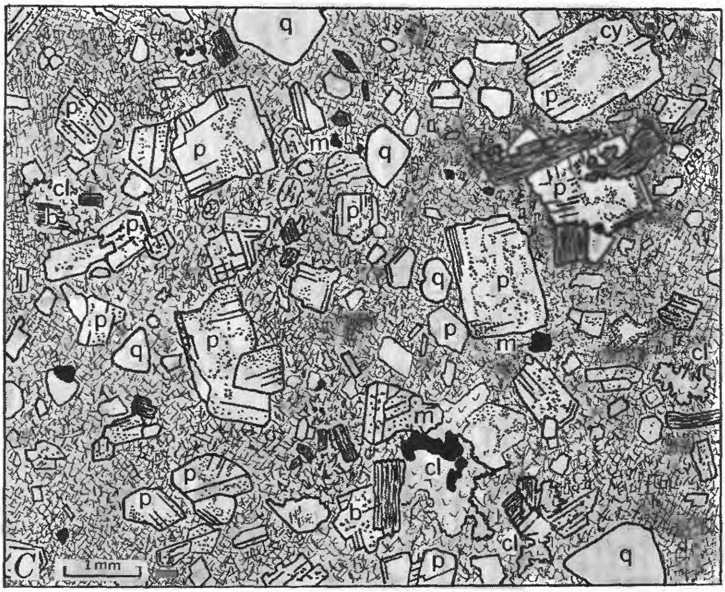


FIGURE 4.—MICRODRAWINGS OF



A. Air-laid tuff of the O'Brien Creek Formation collected from the west end of Castle Mountain in the NW¼ sec. 11, T. 33 N., R. 31 E. Broken crystals of plagioclase (p), quartz (q), and orthoclase (o), together with a few small pieces of magnetite (black), in a matrix of ash.

B. Rhyodacite flow rock of the Sanpoil Volcanics from just east of the north end of Long Lake. Phenocrysts of plagioclase (p), hornblende (h), biotite (b), and magnetite (m) set in a partly divitrified glass. Specimen came from same locality as sample 1 of table 5.

C. Scatter Creek Rhyodacite from a dike on a ridge in the SE¼ sec. 36, T. 34 N., R. 30 E. Phenocrysts of plagioclase (p), quartz (q), biotite (b), and magnetite (m) set in a glassy partly altered groundmass. Chlorite (cl) has formed by alteration from biotite and hornblende, and clay (cy) has formed from plagioclase.

THE VOLCANIC ROCKS

Sanpoil Volcanics are contemporaneous with the Scatter Creek Rhyodacite. Glacial deposits overlie the Sanpoil Volcanics and are the only rocks in the Bald Knob quadrangle that are younger than the volcanics.

DESCRIPTION

More than 90 percent of the Sanpoil Volcanics are flows; the rest are pyroclastic rocks. The flow rocks show an overall variation from northeast to southwest in the Bald Knob quadrangle; in the northeast the rocks tend to weather dull brown and to form flows 5–60 feet thick; in the southwest they tend to weather gray and to contain relatively few flow structures, except in a few places where flow banding is present forming slabby layers ½–3 inches thick. The flows also vary somewhat in mineral composition—the rocks in the northeast tend to be richer in mafic phenocrysts and those in the southwest richer in quartz phenocrysts. Hence, rhyodacite is more common in the northeast and quartz latite in the southwest; both rock types, however, occur in both areas, and the transition from one type to another is generally gradational.

The flows vary from light to dark gray and in some places are greenish or light-brownish gray. Most flows are dense; the only vesicular flow seen occurs along the northern border of the quadrangle in sec. 27, T. 35 N., R. 32 E. The flows are all porphyritic, containing 30–65 percent phenocrysts in an aphanitic groundmass (fig. 4*B*). The most common phenocrysts are white euhedral crystals of plagioclase (An_{44}–An_{59}), which make up 20–60 percent of the rock and average about 35 percent. These crystals range in length from 0.05 to 4.0 mm and commonly show zoning. Twinning is common in many specimens but is partially concealed in some where the crystals have been fractured and then replaced along the fractures by later untwinned plagioclase. Mafic minerals make up 5–18 percent of the rock and consist commonly of hornblende and a little biotite; these minerals generally occur in euhedral crystals that are somewhat smaller than those of plagioclase (fig. 4*B*).

A little more than half the specimens contain 1–4 percent of quartz in small anhedral crystals. Only in a few places in the southwestern part of the quadrangle, however, is quartz visible in hand specimen. Primary magnetite is a universal accessory, ranging from less than 1 percent to as much as 3 percent of the rock. Augite made up 3 percent of the only specimen in which it was found; this specimen was collected in sec. 27, T. 35 N., R. 32 E., along the northern border of the quadrangle. Other accessories, found only in minor amounts in some specimens, are apatite, sphene, and zircon.

In some rocks, the mafic minerals and some plagioclase have been deuterically altered. The most common alteration mineral is chlorite, which where present makes up 1–15 percent of the rock and formed from hornblende and biotite. Other alteration minerals are calcite, which makes up less than 1–4 percent of the rock and formed from hornblende and plagioclase; and epidote, which makes up a trace to 1 percent of the rock and formed from hornblende, plagioclase, and biotite.

The groundmass of the flows is most commonly a light-brown partly devitrified glass. Lath-shaped microlites of plagioclase can generally be recognized. In a few specimens the groundmass is completely crystalline and consists of small anhedral crystals of low birefringence. Specimens from near the base of flows, however, may have a groundmass composed largely of glass; in some of these, a few small spherulites occur, and in others trichites have formed. Many thin sections were tested for potassium with sodium cobaltinitrite using the method of Gabriel and Cox (1929); the results for all specimens indicate that the groundmass contains a considerable amount of potassium, which would occur as a potassium feldspar if the rock were completely crystallized.

The pyroclastic rocks are mainly tuffs, but a few volcanic breccias are found north of the West Fork of the Sanpoil River. Most of these breccias are flow breccias and consist of subangular to subrounded rhyodacite fragments as large as 8 inches in diameter in a matrix of similar material. The breccias contain numerous holes, are generally 10–20 feet thick, and can rarely be traced more than 200 feet. The largest flow breccia, however, is at least 200 feet thick and occurs along the east edge of the quandrangle north of Rattlesnake Gulch. Some of the volcanic breccia is not a flow breccia, but is air laid. One of the air-laid breccias lies below a tuff bed in the NW¼ sec. 8, T. 34 N., R. 32 E., 1 mile northwest of the junction of Gold Creek and the West Fork of the Sanpoil River. The breccia forms a brown cliff about 20 feet high and consists of subangular rock fragments of rhyodacite, black shale, quartzite, phyllite, graywacke, devitrified glass, and crystals or crystal fragments of plagioclase, biotite, augite, hornblende, and magnetite in a brown partly devitrified ash. The rock fragments are $\frac{1}{16}$–8 inches in diameter, and toward the top of the breccia the sizes are fairly well sorted.

Tuffs are found throughout the Sanpoil Volcanics but are not common in most places. Tuffs are common, however, in the eastern part of the quadrangle between North and South Nanamkin Creeks and on the main ridge east of the Nespelem River and south of Kinkaid Creek. Tuff beds are generally discontinuous and can rarely be followed more than a mile. The greater part of the tuff is welded and consists of angular to subrounded rock fragments, crystals, or crystal fragments in a dense matrix of devitrified ash. The rock fragments in some tuffs consist wholly of rhyodacite or quartz latite, and pieces of metamorphosed sedimentary rocks are found in other tuffs. Crystal fragments are similar to those found in the flows and consist of plagioclase, hornblende, biotite, quartz, magnetite, and apatite. Secondary chlorite, epidote, and calcite are present in some specimens. Where both the fragments and matrix are rhyodacitic, the fragments are generally a little darker than the matrix.

Two tuff beds, one overlying the volcanic breccia in sec. 8, T. 34 N., R. 32 E., and the other capping the top of a ridge 1 mile to the southwest, differ from those described above in being unwelded, well sorted, and water laid. These rocks are distinctly laminated and range in grain size from silt to sand. Rock fragments are scarce, but sand-size crystal fragments may make up 50 percent of the rock. Plagioclase is the principal mineral; the rock also contains lesser amounts of quartz, hornblende, biotite, magnetite, and apatite. The rest of the rock consists of partly devitrified ash. Plant fragments occur in the tuff in sec. 8, T. 34 N., R. 32 E., and consist of pieces of twigs, blades of grass, and a few pine needles.

CHEMICAL COMPOSITION

Chemical analyses were made under the supervision of L.C. Peck of three specimens of the Sanpoil Volcanics (table 5). Sample 1 (fig. 4*B*) is typical of the more mafic thick flows, and samples 2 and 3 represent the less mafic relatively structureless rocks of the southwest. Although the oxide content of a given flow may be larger or smaller than the range of oxide content of the three analyzed specimens, petrographic examination indicates that the oxide content of many flows falls within the range of the analyzed specimens. The differences between the analyses of the more mafic and the less mafic flows are best shown by the normative mineral content (table 5), which indicates that the more mafic flows contain more anorthite, hypersthene, diopside, magnetite, hematite, and, ilmenite, and less quartz and orthoclase than the less mafic ones.

Classified on the basis of these chemical compositions according to the system used by Rittmann (1952), specimen 1 is a rhyodacite, and specimens 2 and 3 are quartz latite. As specimens 2 and 3, however, are just on the quartz-latite side of the quartz latite-rhyodacite boundary, most of the Sanpoil Volcanics is probably rhyodacitic.

AGE

The Sanpoil Volcanics, as noted previously, overlies and is therefore older than the O'Brien Creek Formation of Eocene(?) age. It also underlies tuffs in the neighboring Republic quadrangle that contain plant fossils of Oligocene age (Muessig, 1962, p. D59). Hence, from the data available, the Sanpoil Volcanics could be either Eocene or Oligocene in age, rather than just Eocene(?) as suggested by Muessig (1962, p. D57).

TABLE 5.—*Chemical analyses and normative compositions, in weight percent, of the Sanpoil Volcanics*

	Specimen		
	1	2	3
Chemical analyses			
SiO_2	63.08	66.79	67.05
Al_2O_3	15.58	14.87	15.27
Fe_2O_3	2.81	1.29	1.45
FeO	1.61	1.26	1.07
MgO	2.55	1.49	1.38
CaO	4.56	3.34	3.04
Na_2O	3.94	3.59	4.13
K_2O	2.65	3.10	3.11
H_2O-	.98	.33	.75
H_2O+	.90	1.46	1.67
TiO_2	.67	.41	.40
P_2O_5	.26	.15	.15
MnO	.08	.05	.05
CO_2	.06	1.63	.15
Total	99.73	99.76	99.67
Normative compositions			
Quartz	17.70	28.74	23.10
Orthoclase	16.12	18.35	18.35
Albite	33.54	30.39	35.11
Anorthite	16.68	6.39	13.90
Hysperthene	5.00	4.36	3.50
Diopside	3.03		
Magnetite	3.25	1.86	2.09
Hematite	.64		
Ilmenite	1.37	.76	.76
Apatite	.67		
Corundum		3.26	
Calcite		3.70	.40
Total	98.00	97.81	97.21

1. Rhyodacite from just east of Long Lake. D. F. Powers, analyst.
2. Quartz latite from ridge top one-half mile north of Central Peak. D. F. Powers, analyst.
3. Quartz latite from southeast side of a small lake in sec. 18, T. 32 N., R. 31 E. J. W. Goldsmith, analyst.

SCATTER CREEK RHYODACITE

The name Scatter Creek Rhyodacite is given by Muessig (1962) to those porphyritic intrusive rocks that are equivalent in age to the Sanpoil Volcanics. The type locality is a large intrusive body that crops out along Scatter Creek in the Wauconda quadrangle (fig. 1) and whose south end extends into the north edge of the Bald Knob quadrangle just west of Long Lake (pl. 1). The name is also applied to all similar intrusives of approximately the same age in the Bald Knob quadrangle. Pardee (1918, p. 35–36, pl. 1) described and mapped these rocks as porphyry. Large areas of rock mapped by Pardee as porphyry, however, contain interbedded welded tuffs and are now included in the Sanpoil Volcanics. Rocks in the Scatter Creek include both the typical rhyodacite and the somewhat more potassic quartz latite.

The Scatter Creek Rhyodacite occurs as many dikes and intrusive bodies in the Colville batholith and in other rocks in many parts of the quadrangle; it is most commonly found along or within 2 miles of the major northeast-trending faults. Dikes are rarely found in the Sanpoil Volcanics, perhaps owing to the difficulty of distinguishing the intrusives of the Scatter Creek Rhyodacite when surrounded by the similar-appearing rocks of the Sanpoil. The Scatter Creek is probably the same age as the Sanpoil, and parts of the Scatter Creek are younger than certain flows of the Sanpoil and older than others. Some of the larger intrusive bodies, which occur along faults, probably represent fillings of fissures along which the lava rose that formed the flows of the Sanpoil Volcanics. Many of the dikes trend northeast parallel to the trend of the major faults; some, especially in the western part of the quadrangle, trend north or north-northwest. The dip of most of the dikes is steep.

Scatter Creek Rhyodacite is generally a light- to greenish-gray porphyritic rock containing 20–65 percent phenocrysts in an aphanitic groundmass (fig. 4*C*). The most common phenocrysts are white euhedral crystals of plagioclase (An_{30}–An_{53}), which compose 5–50 percent of the rock and range in length from 0.05 to 3 mm. Twinning in the plagioclase crystals is generally poor and zoning is common. Mafic minerals are also visible in hand specimen and make up 1–35 percent of the rock. The most common are hornblende and biotite, which generally form euhedral crystals that are somewhat smaller than the ones of plagioclase. Some specimens contain a few quartz phenocrysts (fig. 4*C*), which compose generally less than 3 percent of the rock; many specimens contain none. Primary magnetite is a universal accessory, ranging from less than 1 percent to as much as 3 percent of the rock. Other accessory minerals found in some specimens are apatite and zircon.

In some dikes, much of the hornblende and biotite and some of the plagioclase has been deuterically altered. Alteration minerals are chlorite ($<$1–20 percent) (fig. 4*C*), which forms from hornblende or biotite; calcite (trace to 10 percent), which forms from plagioclase, hornblende, or biotite; epidote (trace to 2 percent), which forms from hornblende, plagioclase, biotite, or chlorite; sphene ($<$1 percent), which forms from hornblende; and clay minerals ($<$1 percent) (fig. 4*C*), which form from plagioclase. The alteration minerals are commonly pseudomorphs of the minerals they replace.

The groundmass of the Scatter Creek Rhyodacite is microcrystalline. Plagioclase in the form of long, thin microlites is the most conspicuous mineral, but the greater part of the groundmass consists of small anhedral crystals having a low birefringence. Many of the thin sections were stained with sodium cobaltinitrite, using the method of Gabriel and Cox (1929), to check for the presence of potassium. The results indicated that the groundmass is high in potassium, which suggests that potassium feldspar mades up the greater part of the low birefringent anhedral crystals. The rest is probably quartz.

Most hand specimens of the Scatter Creek Rhyodacite are similar in composition, but specimens from 10 dikes that intrude the older metamorphosed sedimentary rocks in the southwest corner of the quadrangle have in part different sizes and types of phenocrysts. These dikes in some places are composed of 5–15 percent quartz in bipyramidal crystals as much as 6.5 mm across, a few widely scattered pink euhedral orthoclase crystals as much as 2.5 cm long, and numerous white euhedral plagioclase crystals as much as 6.5 mm long. Although these dikes appear to be a different rock type because of the presence of quartz and orthoclase phenocrysts and because of the larger size of all phenocrysts, they can generally be traced along strike into the more common type of rhyodacite. Furthermore, a chemical analysis of the large dike of this type (specimen 3, table 6) shows a composition similar to two analyses of the more common type of Scatter Creek Rhyodacite (specimens 1 and 2, table 6); of particular interest is that the normative quartz content of the specimen containing bipyramidal quartz (No. 3, table 6) is lower than that of one of the specimens (No. 2, table 6) in which quartz was not visible in hand specimen and that the normative orthoclase content of specimen 3 is lower than that of both specimens 1 and 2, in which orthoclase was not visible. Thus, the presence of quartz and orthoclase phenocrysts is not dependent on chemical composition. Evidently the dikes containing the bipyramidal quartz crystals represent a facies of the rhyodacite that varies in phenocryst content owing to differences either in pressure and temperature or in the volatile content of magma that formed the dike.

Chemical analyses were made of three specimens of Scatter Creek Rhyodacite (table 6). The variations between analyses are best indicated by the normative compositions, in which the quartz content varies by as much as 6 percent, the orthoclase content by as much as 3 percent, the albite content by as much as 14 percent, the anorthite content by as much as 6 percent, and the hypersthene content by as much as 7 percent. These chemical analyses are like those of the Sanpoil Volcanics (table 5) and vary by about the same amount.

TABLE 6.—*Chemical analyses and normative compositions, in weight percent, of the Scatter Creek Rhyodacite*

	Specimen		
	1	2	3
Chemical analyses			
SiO_2	62.29	69.68	69.83
Al_2O_3	15.54	15.94	15.97
Fe_2O_3	2.19	1.38	.89
FeO	2.31	.52	.71
MgO	2.66	.68	.43
CaO	4.48	1.60	1.96
Na_2O	3.54	4.69	5.21
K_2O	2.96	3.30	2.74
H_2O-	.37	.41	.13
H_2O+	1.34	.86	.79
TiO_2	.72	.33	.26
P_2O_5	.28	.12	.08
MnO	.07	.04	.04
CO_2	.95	.05	.51
Total	99.70	99.60	99.55
Normative compositions			
Quartz	19.50	25.80	25.56
Orthoclase	17.79	19.46	16.12
Albite	29.87	39.82	44.01
Anorthite	14.18	8.06	6.67
Hypersthene	8.02	1.70	1.10
Magnetite	3.25	.70	1.39
Hematite	----------	.96	----------
Ilmenite	1.37	.61	.61
Apatite	.67	----------	----------
Corundum	1.22	1.63	2.04
Calcite	2.20	----------	1.10
Total	98.07	98.74	98.60

1. Rhyodacite from intrusive body on west side of Long Lake. D. F. Powers, analyst.
2. Quartz latite from dike east of Parmenter Creek in SE¼ sec. 12, T. 32 N., R. 30 E. J. W. Goldsmith, analyst.
3. Rhyodacite from dike containing bipyramidal quartz crystals on east side of North Star Creek, 2,000 ft. north of the largest serpentine body. J. W. Goldsmith, analyst.

The Scatter Creek Rhyodacite is classified on the basis of its chemical composition according to the nomenclature of Rittmann (1952). Specimens 1 and 3 (table 6) are classified as rhyodacite, and specimen 2, as a quartz latite. The rocks in this unit range from one rock type to the other. The necessity for using a nomenclature based on chemical classification rather than one based on the quantitative phenocryst content can be seen by comparing the anorthite content measured in thin section (An_{30}–An_{53}) to that calculated from the normative minerals of the three analyses (An_{17}–An_{32}). The difference is due to the fact that the more calcic plagioclase crystallized first and the

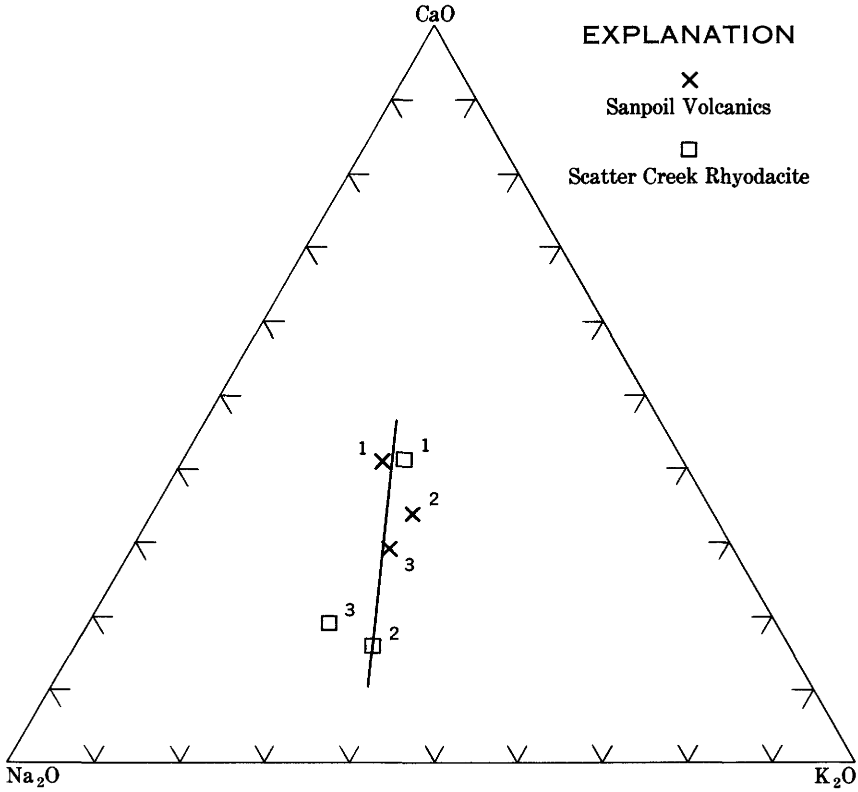


FIGURE 5.—Relation of K_2O, Na_2O, and CaO in the Tertiary volcanic rocks of the Bald Knob quadrangle. Sanpoil Volcanics: 1, flow from just east of Long Lake; 2, flow from ridge one-half mile north of Central Peak; 3, flow from southeast side of small lake in sec. 18, T. 32 N., R. 31 E. Scatter Creek Rhyodacite: 1, intrusive body on west side of Long Lake; 2, dike from east of Parmenter Creek in SE¼ sec. 12, T. 32 N., R. 30 E.; 3, dike from east side of North Star Creek, 2,000 feet north of the largest serpentine body.

rock solidified before these crystals had time to react with the rest of the fluid and become more sodic.

All the dikes of the Scatter Creek Rhyodacite as well as the extrusive rocks equivalent to this formation—the Sanpoil Volcanics—probably came from the same parent magma. Hence, although the chemical composition of these rocks may vary somewhat, the proportions between at least some of the major elements should be relatively constant. Two diagrams, one (fig. 5) having CaO, Na_2O, and K_2O as end members and a second (fig. 6) having MgO plotted against the total iron oxide content,[1] show the relative abundance of some of the major oxides. The points in figure 5 show a linear arrangement

[1] The ratio of FeO to Fe_2O_3 varies considerably in volcanic rocks due to inconsistent degree of oxidation. Hence, the Fe_2O_3 is converted to FeO and the total expressed as ΣFeO.

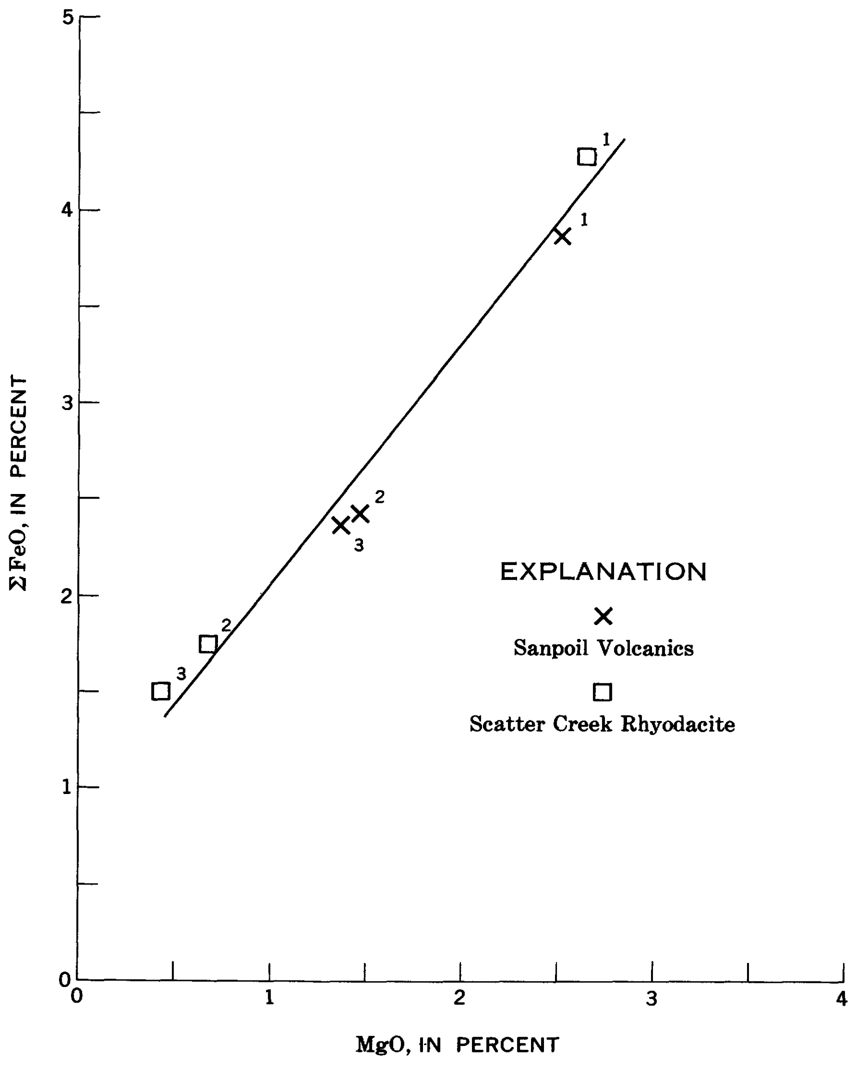


FIGURE 6.—Relation of MgO to total iron oxide in the Tertiary volcanic rocks of the Bald Knob quadrangle. Sanpoil Volcanics: 1, flow from just east of Long Lake; 2, flow from ridge one-half mile north of Central Peak; 3, flow from southeast side of small lake in sec. 18, T. 32N., R. 31 E. Scatter Creek Rhyodacite: 1, intrusive body on west side of Long Lake; 2, dike from east of Parmenter Creek in SE¼ sec. 12, T. 32 N., R. 30 E.; 3, dike from east side of North Star Creek, 2,000 feet north of the largest serpentine body.

and indicate that although the CaO content decreases by nearly 3 percent, the K_2O and Na_2O ratio remains constant. The points in figure 6 show that MgO content increases proportionally as the total iron oxide content increases. Analyses of suites of volcanic rocks from a single source in other regions also show a similar linear arrangement, according to H. A. Powers (oral communication, 1960), if plotted on these types of graphs, but the lines may be in a different position. On the other hand, the analyses of rocks of similar composition but from different areas show no such linear arrangement. Thus, linear relations among the various oxides suggest highly that the rocks came from the same parent magma.

GLACIAL DEPOSITS

Giant piedmont glaciers covered the greater part of the Okanogan Highlands in Wisconsin time (Flint, 1935, p. 171–173). Evidence of at least two episodes of glaciation has been noted 36 miles southeast of the Bald Knob quadrangle near the mouth of the Spokane River (Bretz, 1923, p. 580) and 32 miles west of the quadrangle in the valley of the Okanogan River (Flint, 1935, p. 171). Poor exposures within the Bald Knob quadrangle make it impossible to determine whether that area had been glaciated more than once.

The direction of ice movement across the Bald Knob quadrangle is shown by the 96 glacial striae symbols given on plate 1. Although the average movement was almost due south, locally, as on the west side of Central Peak and on the ridge southwest of the headwaters of Nineteenmile Creek, the direction of ice movement deviated by as much as 60° from this direction.

The ice front in the central Okanogan Highlands was irregularly lobate; one lobe lay across the Columbia River near Coulee Dam (Flint, 1935, p. 189), and another lobe extended down the valley of the Sanpoil River for 24 miles south of West Fork (Pardee, 1918, p. 52). The ice front between these two lobes is imperfectly known and was probably very irregular. Outcrops of till along southern Parmenter Creek, Nespelem River, and Owhi Creek, scattered erratics, and glacial striae, such as those on the hill in the extreme southeast corner of the quadrangle, indicate that the ice front was everywhere south of the Bald Knob quadrangle. The ice covered not only the valleys and the lower ridges but also the higher peaks. An erratic found on the top of Strawberry Mountain, the highest peak in the mapped area, indicates that no nunataks protruded above the ice. The altitude of the top of the icecap in this area is not known, but S. J. Muessig (oral communication, 1958) reported that Bald Mountain, in the southeastern part of the Republic quadrangle, was glaciated to an altitude of 6,750 feet. Thus, the ice may have been as much as 900 feet thick over the highest peak in the Bald Knob quadrangle and as much as 4,750 feet thick over the two lowest valleys, those of the Sanpoil and Nespelem Rivers.

Three types of sediments are related to the glacier or glaciers that covered the Bald Knob quadrangle. These are till, kame terraces, and glacial lake deposits.

TILL

The glacier that moved across the area blanketed the entire quadrangle with a layer of till. The layer is not uniform, as the topography was rugged and greater amounts of till were deposited in deep valleys than on the highlands. Valleys such as those of the West Fork of the Sanpoil River and of the Deerhorn, Anderson, Bear, North Nanamkin, South Nanamkin, and upper Gold Creeks, which lay across the direction of glacial movement (pl. 1), acted like riffles in a sluice and hold thick deposits of till. In some places in the valleys, the till is at least 200 feet thick. On the higher mountains and steep valley walls, the original layer of till was much thinner and has been partly eroded; on many ridges all the finer material has been removed, and only scattered erratics are left.

Patches of till remain, however, over the greater part of the quadrangle, and the till is much more widespread than is indicated on plate 1. (Plate 1 is primarily a bedrock map, and the older rocks are shown as continuous where the outcrops in the till are not more than 500 feet apart.)

The amount of postglacial erosion varies in different areas, depending on the type of material being eroded and on the slope of the hill. A quartz monzonite erratic, 14 feet by 6 feet by 5 feet, lies on the top of the low ridge between Stepstone and North Star Creeks in the northern part of sec. 17, T. 32 N., R. 31 E. This boulder is on a hillside that slopes approximately 15° and rests on a small pedestal of rhyodacite tuff about 2 feet high. While the rest of the hill was being cut down 2 feet, the tuff immediately below the boulder was protected from erosion. As the till is less well consolidated than the tuff, a thicker layer of till than of tuff could be eroded in the same amount of time under the same conditions.

The till in most places is covered by vegetation. Where exposed, it ranges in composition from well-sorted gravels and sands to a compact clayey till. The greater part of it, however, contains boulders scattered in a matrix of gravel, sand, granule-sized particles and some silt and clay. Boulders as large as 20 feet across have been seen, but most of them do not exceed 1 foot in diameter. The boulders and gravel are angular to well rounded and are indistinctly stratified. The degree of rounding depends not only on the distance traveled but also on the rock type. Quartz monzonite occurs generally as rounded boulders; rhyodacite, as subrounded to subangular boulders; quartzite, as subangular boulders; and phyllite and shale, as tabular angular boulders. Most of the larger boulders are composed of quartz monzonite, because this rock is not only abundant but also resistant to wear. The resistance of a rock can be estimated from the distance that a boulder was carried by the glacier before it broke into smaller pieces. Boulders of quartz monzonite have been found at least 10 miles south of its nearest source; rhyodacite is rarely found as much as 2 miles from its nearest source; and phyllite and shale boulders were rarely transported farther than 100 yards. Hence, the presence of phyllite or shale boulders indicates that the source is close by. Pieces of metamorphosed sedimentary rocks are more common in the finer sizes (gravel, granule, and sand). Boulders are generally plentiful in the till but are irregularly distributed. Gravels, granules, and sand also are irregularly distributed in some places, but in other places, they occur in sorted layers.

KAME TERRACES

Kame terraces are found along the sides of a few of the valleys (pl. 1), where they formed after the till was deposited and after the glacial ice had wasted away so that it was present only as tongues along the deeper valley bottoms. These deposits formed between the valley walls and the ice masses in the center of the channels. The tops of the terraces are either flat or slope up the sides of the valley and are as much as 250 feet above the present stream channels. Commonly, the tops of the terraces slope gently downstream. The kame terraces are most extensive along the West Fork of the Sanpoil River, where two terrace levels extend for 4½ miles along the river. The lower terrace, having an upper edge at an altitude of about 2,250 feet, occupies the north side of the river from about 1 mile west of West Fork to about 1 mile west of the mouth of Gold Creek. The higher terrace, having an upper edge at an altitude between 2,320 and 2,400 feet, occupies both sides of the valley west of the lower terrace to a point about 3 miles above Gold Creek and south of the river west of the mouth of Gold Creek. Thus, from the mouth of Gold Creek to about 1 mile west of Gold Creek both terraces occur in the valley; the lower terrace lies on the north side of the river and the upper terrace lies on the south side. The upper terrace is generally much broader and in places is half a mile wide.

The kame terraces consist generally of well-sorted, crudely stratified layers of sand and gravel. Most pebbles are ½–1 inch in diameter and are well rounded. Some boulders are found scattered through the terraces. Glacial boulders as large as 15 feet in diameter litter the upper terrace surface on the north side of the West Fork of the Sanpoil River. The composition of the boulders and pebbles is similar to that found in the till. The upper terrace along the West Fork of the Sanpoil adjacent to phyllite, phyllitic quartzite, and graywacke is unusually rich in these rocks.

The kame terraces resemble terraces formed by streams. They are probably kame terraces, however, for the following reasons: (1) Some of the material within the terraces is similar to that on the valley walls rather than that derived from upstream; (2) the tops of some of these terraces slope up the valley walls, a fact which also suggests that some of the material came from the valley walls; (3) several kettles are seen on terraces on the north side of the West Fork of the Sanpoil River; (4) commonly, the terraces are irregularly distributed along the sides of the valleys and are neither as continuous as most stream terraces nor paired on the opposite sides of the valley, as are most stream terraces; and (5) the presence of adjoining terraces at two levels, as along the valley of the West Fork of the Sanpoil River, is a common feature of kame terraces (Flint, 1947, p. 147). Later erosion and thick vegetation has made it difficult to distinguish the smaller kame terraces from the underlying till. The major kame terraces are shown on plate 1.

GLACIAL LAKE DEPOSITS

Lake deposits are found in scattered patches on the west side of Gold Creek from the mouth of Deerhorn Creek to a point about 1½ miles to the southwest. These deposits were formed in a steep-sided narrow lake created when Gold Creek was blocked near its mouth by ice. The upper edge of the sediments indicates that the altitude of the surface of the lake was as much as 2,700 feet. Little remains of the sediments, owing to accelerated erosion in this narrow valley when the ice dam melted. The best exposure of the lake sediments is found in the scar of a small landslide on the hillside due west of the mouth of Deerhorn Creek. Here, the lake deposits consist of about 70 feet of crudely stratified well-sorted sand and well-rounded gravel that contains cobbles as much as 6 inches in diameter; they are overlain by about 100 feet of light-buff very fine sand. The sand is well sorted, having a coefficient of sorting (So) of 1.38, and has a median grain diameter of 0.098 mm. The sand consists mainly of angular grains of quartz and a minor amount of phyllite, quartzite, biotite, hornblende, and muscovite. In the sand are found small tubular structures about 1 mm long that are formed of tiny quartz particles fastened together by a calcareous cement. These structures were identified by P. E. Cloud, Jr. (written communication, 1958), as cases of caddis fly larva. Cloud stated: "Since these curious animals spend most of their lives in the larval state in streams, ponds, and lakes, the small larval cases are common in fresh water sediments."

The very fine sand near the mouth of Deerhorn Creek is similar in appearance to the Nespelem Silt along the Columbia River described by Pardee (1918, p. 28–29). The Nespelem Silt was formed in a glacial lake that was formed by the damming of the Columbia River somewhat west of Coulee Dam. The two sediments are similar because they are formed of similar materials, under similar conditions, at about the same time. The very fine sand near the mouth of Deerhorn Creek, however, is not the Nespelem Silt, as it formed in a separate lake at a different altitude. At its greatest extent, the lake along the Columbia River reached an altitude of about 1,700 feet; the lake near the mouth of Deerhorn Creek reached an altitude of at least 2,700 feet.

STRUCTURE

The structure of the Bald Knob quadrangle is moderately complex and involves folded bedding and schistosity and faults having diverse trends. The dominant structural features trend north to northeast, and of these the most pronounced is the Republic graben (fig. 7), which includes about two-thirds of the quadrangle. The faults that bound the graben are the most significant structural features in this area.

At least two periods of deformation are recorded. The first occurred after all the metamorphosed sedimentary and metamorphosed igneous rocks were emplaced but before the intrusion of the diorite; the second started prior to the emplacement of the Colville batholith and ended after all the rocks in the quadrangle except the glacial deposits were emplaced. Rocks that have undergone two or three periods of deformation differ from those having undergone only one in having more folds and faults, steeper dips, and faults of several trends. As the amount and kind of deformation that occurred in each period cannot always be distinguished, the structure of the older metamorphosed sedimentary and metamorphosed igneous rocks and of the intrusives and volcanic rocks are discussed separately.

STRUCTURE OF THE METAMORPHOSED SEDIMENTARY AND METAMORPHOSED IGNEOUS ROCKS

The metamorphosed sedimentary and metamorphosed igneous rocks form a discontinuous northeast-trending belt extending through the center of the quadrangle. Because their detailed stratigraphy is imperfectly known, only a general picture of their structure was obtained. North of the West Fork of the Sanpoil River, several small quartzite marker beds aid in making a more complete picture of the structural features within the phyllite. As the structure of the metamorphosed sedimentary and metamorphosed igneous rocks is different in each of the three areas, the structure of each area will be discussed separately.

In the northern part of the quadrangle, northwest of the Long Lake fault, the structural features of the rocks are different on the two sides of the fault that extends between phyllite and phyllitic quartzite. To the west of this fault, greenstone and phyllitic quartzite strike northward and dip moderately to steeply eastward (pl. 1). Drag folds plunge shallowly to the southeast or the northwest. To the east of this fault the phyllite has been folded in at least four northward-trending folds, some of which are overturned. The axes of the folds, as well as those of drag folds, have a moderate southerly plunge. The fault separating phyllite and phyllitic quartzite is the only fault recognized in this area. The fault surface is nowhere exposed, and its presence was determined by the changes in dip of bedding and foliation and the abrupt ending of a massive quartzite bed in the phyllite. In the rocks west of the fault the top sides of the beds are to the east, as determined in several places in the phyllitic quartzite by the angle between the cleavage and bedding and in the greenstone, by the shapes of pillows in a pillow lava.

The structure of the older rocks in the northern part of the area southeast of the Long Lake fault is somewhat different from that in the area north of the fault. Although northward-trending folds are predominant, as they are north of the fault, they plunge northward instead of southward. The largest structural feature is a broad anticline, whose axis strikes N. 10° E. along Gold Creek and plunges about 35° N. The west limb of this fold is cut by the Long Lake fault. In the graywacke west of this fault, although the foliation of the rocks dips 28°–72° E., the bedding is nearly vertical. If the rocks west of the King Creek fault form a part of this anticline, which seems likely, then the axial plane of the anticline has an easterly dip. A small syncline and anticline occur in graywacke on the east side of the broad anticline that is found half a mile west of Bald Knob; the anticline is well exposed on the south side of Gold Creek, where a thin bed of graywacke conglomerate outlines the structural feature. To the west, the metamorphosed sedimentary rocks adjacent to the Long Lake fault are flattened out in some places by drag.

Black shale unit No. 1 and the few small metadiorite intrusives found in the center of the quadrangle are 1–1½ miles south of the phyllite and graywacke to the north and are separated from them by an eastward-trending bulge of the Colville batholith. The abrupt change from graywacke to phyllite on one side of the bulge to shale a short distance away on other side indicates that the bulge was intruded along a major fault. As the strike of the fracture that is followed by the bulge is approximately parallel to the fracture followed by the granodiorite porphyry intrusion 6 miles to the southwest and as both fractures cut metamorphosed sedimentary rocks and were formed before the batholith, the fractures probably formed at the same time. These two fractures are not parallel to any other fractures and may have formed during a separate period of deformation.

In general the shale in the central area is so intricately folded that only a few of the larger folds can be shown on the map (pl. 1). A well-defined southwestward-plunging syncline occurs in the black shale on the west side of the Nespelem River fault (pl. 1), and a well-defined northwestward-plunging anticline occurs in the shale on the east side. The intrusive force of the batholith has greatly complicated the earlier structure of the black shale in most of the area. The batholithic rocks bound the area to the north, are exposed in a small stock to the south, and have been found underground in some of the mines. As the batholith is at a maximum only a few thousand feet below the shale east of the Nespelem River fault, the shale is here not only more intricately folded than in the area west of this fault but also contains numerous fractures. On Castle Mountain (pl. 1) the beds of black shale commonly vary greatly in strike and dip over a few tens of feet.

The schist in the central part of T. 33 N. west of the Long Lake fault is cut by an east-trending dike of granodiorite porphyry, which follows an east-trending fracture. Drag-fold axes and mineral lineations in this area plunge gently to the northwest.

The much larger area of metamorphosed sedimentary and metamorphosed igneous rocks 2 miles south of this area in the southwestern part of the quadrangle has a somewhat different structural pattern. Here the beds have a general northeasterly strike and southeasterly dip, except to the northwest, where beds of schist are folded into a northeast-trending anticline. The axes of drag folds plunge in several directions: in the northern part of this area they plunge moderately to the east; adjacent to faults they generally plunge shallowly toward the fault; and in the southern part of this area they commonly plunge shallowly toward the south.

Two groups of faults occur in this southwestern area—an older northwest-trending group and a younger northeast-trending group. Exposures of all faults are poor. Although the fault surfaces are not exposed, the older group has probably an almost vertical dip; the younger group, a moderate dip to the east. The northeast-trending faults are apparently part of the Scatter Creek fault zone that forms the west margin of the Republic graben (fig. 7). The largest fault is the Long Lake fault, which forms the east-west margin of the metamorphic rocks, and the other northeast-trending faults split off this main fault. The branch fault having the largest displacement splits off the Long Lake fault at Stepstone Creek and rejoins it at Parmenter Creek. Its exact trend and dip, however, are difficult to determine, as the largest serpentine body was intruded along it. The movement on this fault is indicated by black shale unit No. 2, which is found both in an outcrop band ⅝–1 mile northwest of the fault and again on the southeast side of the fault. The minimum vertical displacement on the fault necessary to account for displacement of the shale unit is 5,000 feet. The next largest fault is about 1 mile northwest of the Long Lake fault and has been traced for 3½ miles in the Bald Knob quadrangle. This fault dips approximately 35° SE. A minimum vertical displacement of several thousand feet is necessary to account for the termination of the quartzite along its southwest end.

STRUCTURE OF THE INTRUSIVE AND VOLCANIC ROCKS

The volcanic and intrusive rocks have been subject to faulting, folding, and jointing. All outcrops of the Sanpoil Volcanics and the O'Brien Creek Formation are within the Republic graben, and the deformation and emplacement of these rocks appear related largely to this structural feature. Structural features in the instrusive rocks outside the graben consist of foliation and joints, which are commonly intruded by dikes of Scatter Creek Rhyodacite.

STRUCTURAL FEATURES WITHIN THE REPUBLIC GRABEN

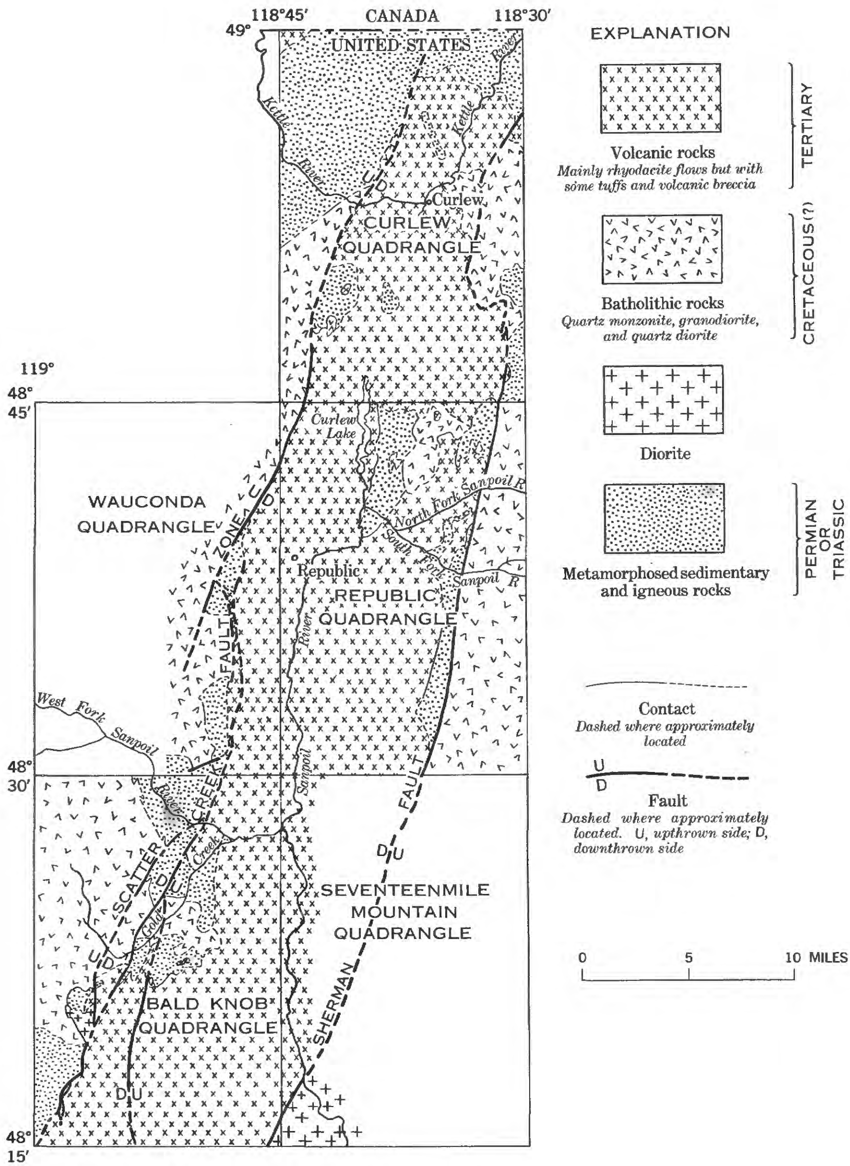
Only a part of the Republic graben lies within the Bald Knob quadrangle (fig. 7). The graben was mapped in detail by Calkins, Parker, and Disbrow (1959) in the Curlew quadrangle, by Muessig and Quinlan (1959) in the Wauconda and Republic quadrangles, and by me in the Bald Knob quadrangle. The north end of the graben is in the northern part of the Curlew quadrangle[2]; it trends from there south-southwest for 52 miles to the southern end of the Bald Knob quadrangle. The graben has not been traced south of the Bald Knob quadrangle, but it could probably be traced for another 14 miles to the Columbia River; south of the river, the area is covered by Columbia River Basalt. The graben ranges in width from 4 to 10.5 miles; it is 9.5 miles wide in the southern part of the Bald Knob quadrangle.

FAULTS

The graben is bounded on the southeast by the Sherman fault and on the northwest by several branching faults that make up the Scatter Creek fault zone (fig.7). This fault zone comprises three main faults in the Bald Knob quadrangle (pl. 1)—the Long Lake, the King Creek, and the Nespelem River faults.

The longest fault in the Scatter Creek fault zone is the Long Lake fault, which has been traced from Long Lake on the northern boundry of the quadrangle to the southwest corner of the quadrangle. This

[2] The fault on the northwest side of the graben apparently ends in the northern part of this quadrangle, as it was not found in British Columbia (Little, 1957). The fault on the southeast side of the graben has been traced for about 75 miles into British Columbia by Little (1957).



Geology in the Curlew quadrangle by Calkins, Parker, and Disbrow (1959); in the Republic and Wauconda quadrangles by Muessig and Quinlan (1959); and in the Bald Knob quadrangle by M. H. Staatz

FIGURE 7.—Generalized geologic map of the Republic graben.

fault is not exposed south of King Creek or north of the creek that enters Gold Lake, and its position here is determined by topographic expression; the fault is well exposed, however, between Deerhorn and King Creeks, where it follows a trench separating batholithic rocks from crumpled graywacke. A breccia zone as much as 150 feet thick marks the fault in places in the southwestern part of the quadrangle. The zone consists of generally rounded fragments, heterogeneous in size and as large as 1 foot in diameter, in a fine-grained dark greenish-gray gouge. The fragments are composed of quartzite, shale, phyllite, graywacke, vein quartz, rhyodacite, diorite, limestone, or serpentine. The vault dips 35°–50° SE, the dip becoming flatter to the south. Drag along the fault and the distribution of batholithic rocks on either side of it suggest that the east side of the fault moves down and to the south relative to the west side. The amount of movement is not known, but the minimum vertical displacement as estimated from the amount of movement it would take to put the lowest volcanic rock on top of the highest metamorphosed sedimentary rock is 1,600 feet; the actual vertical displacement is probably several times this figure.

The King Creek fault branches off the Long Lake fault in the valley of the West Fork of the Sanpoil River and rejoins it 12 miles southwest in the valley that is east of Stepstone Creek; the fault is best exposed south of Strawberry Creek. The trend of the King Creek fault indicates that the fault dips moderately to the southeast. Offset of the graywacke indicates that the King Creek fault is a reverse fault, the east side moving up and to the north relative to the west side. Horizontally, the fault apparently offsets the quartz monzonite-metamorphosed sedimentary rock contact about 1 mile between Strawberry and King Creeks, although a part of this apparent offset may be due to an irregular intrusive contact. The amount of vertical movement is not known.

The Nespelem River fault branches off the King Creek fault on King Creek and trends south at least to Owhi Lake, on the southern boundary of the quadrangle. Although the Sanpoil Volcanics is on both sides of the fault for about three-quarters of its length in the Bald Knob quadrangle, the position of the fault throughout most of its length is clearly marked by valleys. Parts of King Creek, Nespelem River, Kinkaid Creek, and the creek that flows south into Little Owhi Lake follow the fault. Between these streams, the fault crosses shallow divides. East of Kinkaid Creek, the fault lies in a trench that crosses three small ridges (pl. 1). The fault is best exposed on the west end of Castle Mountain, where it lies in a narrow trench separating O'Brien Creek Formation from black shale unit No. 1. Where this fault follows the Nespelem River valley, the volcanic rocks along the fault are silicified and contain numerous small partly oxidized cubes of pyrite. Differences also exist in some of the Sanpoil Volcanics on the opposite sides of the fault; on the west side of the Nespelem River fault west of Little Owhi Lake, the volcanic rocks consist of more than 50 percent tuff; those on the east side of the fault consist of less than 1 percent tuff. The dip of the fault is not known, but its trace suggests that it is nearly vertical. The east side of this fault moved up relative to its west side. Its approximate vertical displacement as measured by the offset of the contact between the O'Brien Creek Formation and the Sanpoil Volcanics west of Central Peak is 4,700 feet. The amount of horizontal movement, if any, is not known.

In addition to the three main faults, several short faults split off the Long Lake fault in the southwest corner of the quadrangle. The two largest of these cut the metamorphosed sedimentary rocks and are described on pages F53–F54.

The Sherman fault, which forms the southeast side of the Republic graben, crosses the southeast corner of the Bald Knob quadrangle; only 1¾ miles of its trace lies within the area mapped. Within the quadrangle this fault is not exposed and follows several valleys; the northernmost valley is a part of Cub Creek. The straightness of the trace of this fault (fig. 7) both in the Bald Knob and in the adjoining Seventeenmile Mountain quadrangle, where I traced it by reconnaissance for 8 miles to the northwest, suggests that the dip of the fault is nearly vertical. The direction of horizontal displacement is not known, but the east side of the fault moved up relative to the west side.

FOLDS

The strikes and dips in the O'Brien Creek Formation and in tuffs in the Sanpoil Volcanics are very diverse in most parts of the quadrangle (pl. 1), and the fold pattern is not clear. The attitudes are most uniform in the southeast quarter of the quadrangle, where most of the tuff beds strike north and dip moderately to the east. The diversity in strike and dip of the beds is probably not due to intricate folding of all the volcanic rocks. It is more likely due either to original dip, as the tuffs may have been deposited on inclined slopes with their original strike in any direction and their original dip rather steep, or to folding of the older parts of the volcanic rocks, which took place over a longer period of time than did the folding of the younger parts. Evidence for folding is found west of the junction of Gold Creek with the West Fork of the Sanpoil River. Here, at the base of the volcanic section, the older O'Brien Creek Formation strikes northeast and dips moderately to steeply northwest; at the top of the volcanic section, a small tuff bed in the overlying Sanpoil Volcanics also strikes northeast but dips 17° SE. Folding of these rocks appears to have taken place at various times during the emplacement of the volcanic rocks.

FORMATION OF THE GRABEN

The Republic graben subsided during a considerable period of time in the early and middle Tertiary. The formation of the graben is closely tied to the eruption of the volcanics; hence, the history of the graben is also that of the volcanic rocks.

The early Tertiary was a time of considerable igneous and structural activity, which occurred in this order: (1) formation of small rifts along a structurally weak zone now occupied by the graben, (2) deposition of tuffs and breccias, (3) start of extrusion of a large volume of lava, (4) intrusion of the Tertiary batholith exposed in the Republic quadrangle, (5) start of subsidence of the graben, and (6) continued extrusion of lava flows with renewed subsidence.

As can be seen in figure 7, the Tertiary volcanic rocks occur almost exclusively within the graben. The first volcanic rocks were the tuff and breccia of the O'Brien Creek Formation, which were laid down as an irregular blanket over the metamorphosed sedimentary and batholithic rocks. In places, the tuffs are well stratified, indicating that they were water laid.

The deposition of the O'Brien Creek Formation was followed by deposition of the Sanpoil Volcanics, a thick sequence of rhyodacitic flows containing some interbedded tuffs. The Republic graben started to sink soon after the earlier flows of the Sanpoil Volcanics were extruded.

The faults that bound the edges of the graben probably acted as conduits along which some of the lava first rose. Some of the larger bodies of Scatter Creek Rhyodacite (the intrusive equivalent of the Sanpoil Volcanics) are found in or adjacent to the boundary faults—for example, the intrusive west of Long Lake and the one west of Bald Knob. This fact is even more apparent in the Republic quadrangle (Muessig and Quinlan, 1959), where many of the larger bodies of Scatter Creek Rhyodacite are adjacent to the Sherman fault. Lava also rose along fissures within the graben, as is indicated by large bodies of Scatter Creek Rhyodacite near the head of Anderson Creek and in the Republic quadrangle.

Although most of the flows were deposited in the graben, a few smaller ones may have been deposited outside it, as suggested by the presence of many dikes of rhyodacite west of Gold Lake.

A thick breccia zone found on the Long Lake fault half a mile west of North Star Creek indicates that movement on the faults continued during the emplacement of Sanpoil Volcanics. Here the breccia zone contains fragments of rhyodacite, indicating that some of the movement followed the emplacement of some rhyodacite; however, a few feet away the breccia is cemented by a later rhyodacite, indicating that some of the faulting preceded the emplacement of some of the volcanic rocks.

Presumably the graben sank as these thick flows were extruded. The sinking of this block would have been aided by the weight of the volcanic rocks. If the magma came from beneath the graben, then the graben could have easily sunk into the space from which the volcanic material came.

Near Republic another sequence of pyroclastic material (the Klondike Mountain Formation of Oligocene age) was deposited on the Sanpoil Volcanics (Muessig and Quinlan, 1959). The upper part of this sequence, which may be as young as Miocene, lies wholly within the graben and is cut by the western boundary fault. Hence, movement on the boundary faults probably continued to at least Miocene time.

The rock units within the Republic graben were tilted and folded as the graben subsided unevenly. Rocks were deformed throughout most of the history of the graben, as shown by angular unconformities in the Tertiary rocks. As noted on pages F57–F58, a tuff bed in the Sanpoil Volcanics west of the junction of Gold Creek with the West Fork of the Sanpoil River, is tilted in the opposite direction from the tuffs in the underlying O'Brien Creek Formation; presumably the formations are separated by an angular unconformity. The Tom Thumb Tuff Member of the Klondike Mountain Formation in the Republic quadrangle is separated from the underlying Sanpoil Volcanics by an angular unconformity (Muessig and Quinlan, 1959), and the upper two members of the Klondike Mountain Formation are also separated from the Tom Thumb Member by an angular unconformity. Tilting of the upper two members of the Klondike Mountain Formation indicates that they too were deformed after their emplacement. The evidence indicates folding or tilting of the volcanic rocks at least five different times. Actually, the rocks may have been deformed more or less continuously during the subsidence of the graben.

During and since the formation of the graben, the rocks of the region were eroded. The rocks outside the graben, because they were rising, were eroded more than those within the graben, which were sinking. If any of the O'Brien Creek Formation and Sanpoil Volcanics were deposited on the rocks outside the graben, they have been stripped away. The mountains today are subdued and have flat rounded tops. Within the Bald Knob quadrangle, relief is about the same both in and outside the graben.

STRUCTURE OUTSIDE THE REPUBLIC GRABEN

The structural deformation outside the graben in the batholithic rocks, diorite, and Scatter Creek Rhyodacite is much less extensive than that within it. No faults nor folds have been found, and the only recognizable structural features are foliation and jointing.

The greater part of the batholithic rocks lacks structural deformation. Foliation is found locally but, in general, is not predominant. The Bald Knob quadrangle does not contain any rocks similar to the extensively banded, intricately swirled, and highly granulated rocks that make up the protoclastic border of the Colville batholith along the Okanogan River (Waters and Krauskopf, 1941). Foliation in the mapped area was inherited from the older metamorphosed sedimentary or metamorphosed igneous rocks or was formed during faulting or by movement within the intrusive before all the rock was completely consolidated. The foliation of the batholithic rocks is discussed in greater detail on pages F29–F30, in the section discussing the Colville batholith.

Joints are rare in the intrusive rocks, and in wide areas none are visible. In a few areas, as on Strawberry Mountain, two sets of joints are present. The most common set, and the only one present in much of this quadrangle, has a northerly strike and a steep westerly dip. Other joints have a highly variable strike and dip and are apparently related to local features. Dikes of Scatter Creek Rhyodacite are commonly intruded along joints. Such dikes are most common in the area west of Gold Lake, where their trend (pl. 1) indicates the trend of the most extensive joints.

GEOMORPHOLOGY

The Okanogan Highlands consist of a jumble of mountains having no particular trend and moderately undulating upland surfaces cut by deep valleys. The upland surfaces are commonly well rounded and represent a fairly mature stage of erosion; the major stream valleys are steep sided and represent a youthful stage of erosion. The land has been elevated since the more mature highlands were eroded, and a second cycle of erosion has started with the cutting of deep valleys.

Within the Republic graben all the flat-topped land surfaces are not due primarily to erosion, as the undulating surface on the Sanpoil Volcanics is similar to that found on thick flows in areas where little erosion has taken place. Thus, although this upland surface has undoubtedly been changed during an early period of erosion, its shape is in large part due to the original shape of the surface of the thick series of flows.

Pardee (1918, p. 44), however, believed that the relatively flat-topped ridges in the western part of the Seventeenmile Mountain quadrangle and in the eastern part of the Bald Knob quadrangle extending into the Gold Creek basin were fairly concordant and were originally part of a peneplain-type upland surface, which he called the Sanpoil erosion surface and which has an altitude of approximately 3,500 feet. Modern topographic maps of the Bald Knob and Seventeenmile Mountain quadrangles indicate, however, that the ridge summits are not nearly as concordant as they appeared to Pardee; altitudes of the flat ridge tops range from about 3,300 to 4,100 feet. Hence, the Sanpoil erosion surface is not a peneplain-type surface as implied by Pardee (1918, p. 44).

The well-rounded uplands are cut by the steep-sided valleys of the Sanpoil, West Fork of the Sanpoil, and Nespelem Rivers and of the Owhi, Anderson, Bear, North Nanamkin and South Nanamkin Creeks; in places most of these valleys have slopes of more than 30°. Locally, as along the headwaters of the Nespelem River, parts may slope more than 60°. These valleys may have originated during the earlier period of erosion, although the ancestral channels of some, such as the Sanpoil River, which in part follows the center of the Republic graben, may even have preceded the extrusion of most of the volcanic rocks. As the land surface became more mature, the gradient of the streams became less and they meandered probably more on the mature surface than they do today. The mature surface was then uplifted and the cutting power of the streams was increased. When this uplift occurred is not certain, but it preceded Pleistocene glaciation, for the valleys formed after this uplift contain till. The period of time since the latest uplift was less than the period of time between the two uplifts; the land has reached only a youthful stage of erosion since the latest uplift, but reached a mature stage after the earlier period of erosion. Perhaps the uplift occurred in Pliocene time.

The steep-sided valleys were formed in part prior to glaciation, but they were also deepened considerably during glaciation. Some streams, such as the Sanpoil River, are underfit. The valleys of these streams may have been carved in part by the glacier, but the greater part of the erosion took place when the glaciers melted and the streams and rivers were swollen with a large volume of water. Hence, the time of glacial recession was a period of accelerated erosion.

The glaciers also either temporarily or permanently changed the courses of some streams. As the glacier moved slowly southward, northward-flowing streams, such as Gold Creek, were dammed, and in some places the flow was reversed. Streamflow was stopped when the channels became completely filled with ice but started again as the ice receded.

Changes in the direction of flow and course of Gold Creek and part of North Nanamkin Creek are shown by abandoned channels and by tributaries that flow in the opposite direction from these main streams. These tributaries, within certain limits, are highly significant in showing whether or not the stream has always flowed in the same direction as at present. In drainage systems cut in a fairly uniform type of rock that has not been structurally deformed for a long time, the tributaries all tend to flow in the same direction as the main stream. Thus, one going down a stream of this kind will observe that branches coming in from the right and the left approach the stream gradually and join it at acute angles. On the other hand, if the acute angles of juncture between the tributaries and the main stream, as a rule, point up the main stream, then the trunk stream during relatively recent geologic time flowed in reverse of its present direction. Evidence of this sort indicates that Gold Creek, which now drains northward, once drained southward. The direction of flow of lower Deerhorn, King, and Strawberry Creeks is opposite to that of the present Gold Creek, a fact indicating that Gold Creek flowed south. The course of this southward-flowing stream is indicated west of Gold Lake by an old abandoned channel that passes through the center of sec. 17, T. 33 N., R. 31 E. This abandoned channel connects the present Gold Creek drainage with a valley that is now followed by the creek that lies east of Stepstone Creek. Gold Creek once flowed south because it was dammed by ice between Deerhorn Creek and the West Fork of the Sanpoil River. The lake sediments along Gold Creek near the mouth of Deerhorn Creek indicate that a lake was formed. When the ice dam melted, the water flowed north, and the south-flowing part of Gold Creek lost much of its volume; thus its cutting power was greatly decreased. After glaciation, Stepstone Creek cut back to the north and finally captured the segment of Gold Creek that lies in the Bald Knob quadrangle between the west edge of the quadrangle and a point about 2 miles west of Gold Lake.

An abandoned channel in the SW¼ sec. 5, T. 32 N., R. 32 E. (fig. 8), and one tributary pointing upstream indicate that the upper part of North Nanamkin Creek once flowed south and joined South Nanamkin Creek. The upper part of North Nanamkin Creek probably flowed south during the late stages of glaciation, when a tongue of ice near the junction of secs. 27, 28, 33, and 34, T. 33 N., R. 32 E., blocked its flow to the east. The presence of an ice tongue at this locality is demonstrated by prominent kame terrace deposits (pl. 1), which formed between the ice tongue and the valley wall.

Glacial ice also rounded off many of the ridges, gouging out some areas and leaving other areas relatively untouched. Ridges, especially those in the batholithic rocks, are very irregular and have many small knobs separated by deep narrow defiles. Small hollows have been scooped out along many ridges and are commonly occupied by

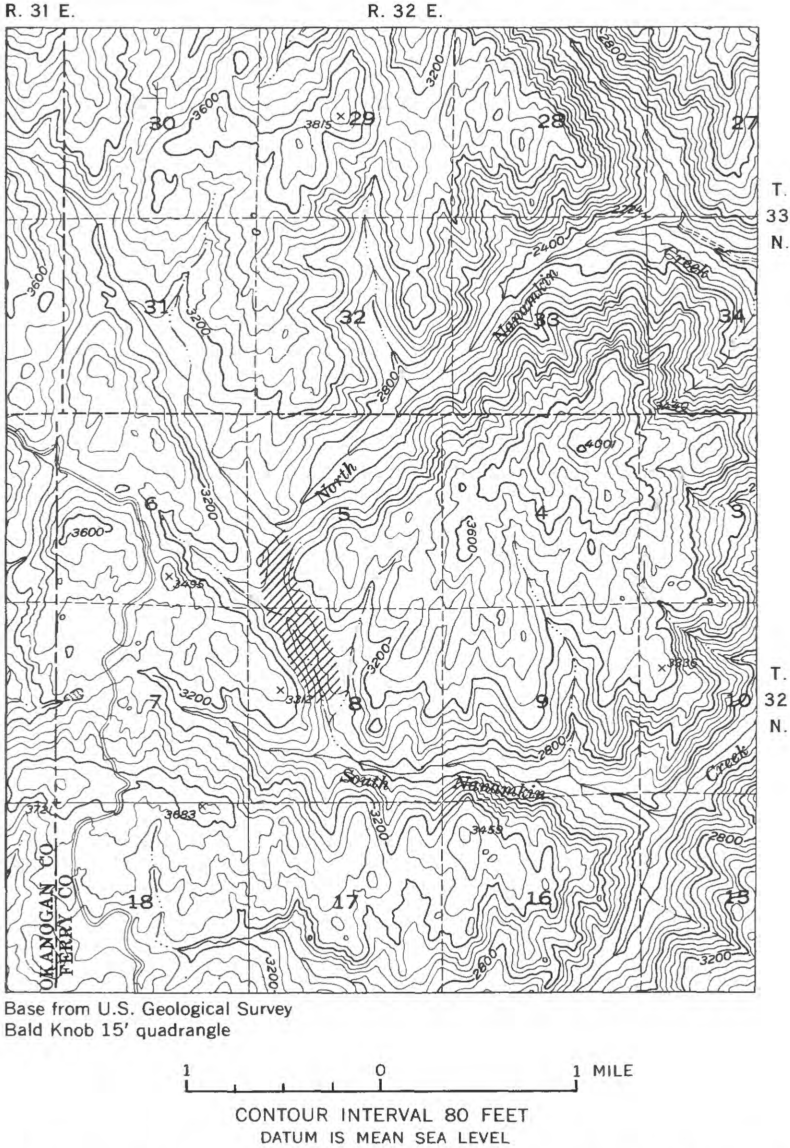


FIGURE 8.—Map showing old channel (shaded) through which the southern part of the present North Nanamkin Creek drained southward and joined South Nanamkin Creek during glacial times.

shallow ephemeral ponds, generally not more than 100 feet long. The upland valleys, like the heads of Strawberry and Gold Creeks, on the other hand, were filled with glacial till so that irregularities in slope were lessened and broad basins were formed. Since the last glacier receded, the major streams have cut through much of the glacial till in their lower courses.

MINERAL DEPOSITS

The Colville Indian Reservation was open to mineral entry in 1896 (Pardee, 1918, p. 53) and closed in 1934 (Van Nuys, 1953, p. 18). The number of claims located in the Bald Knob quadrangle during these 38 years were not large, and only two groups having a total of 9 claims were patented. These consist of the Park-Central group on Central Peak (Central, Park, Tip Top, Monument, and Apex claims) and the Ramore group about 1 mile west of Central Peak (Ramore, Gertrude, Sulphur, and Gladore claims). All other claims are unpatented, and as little work has been done in the district for 40 years, few claim posts remain. Hence, the location of many of the properties is not well known. The names of the unpatented claims as used by Bancroft in 1910 (1914, p. 205–209), Pardee in 1913 (1918, p. 93–102), and Patty in 1919 (1921, p. 189–192) are used in this report for convenience in referring to a property and for ease in comparing this paper with the earlier reports. In 1958 and 1959 the Bureau of Land Management inspected all unpatented claims in the area for the purpose of condemning those of little economic value.

Two types of lode deposits are found in the Bald Knob quadrangle: lead-silver deposits and chromium-nickel deposits. In addition, small gold placers have been mined near the mouths of Strawberry and Gold Creeks and on the West Fork of the Sanpoil River.

LEAD-SILVER DEPOSITS

GENERAL DISCUSSION

The lead-silver deposits lie chiefly in an area about 2 miles wide between Gold Lake and Central Peak. This area is called the Park City district after a few prospectors' cabins that were grouped just east of a wooded park on the southwest side of Castle Mountain (Pardee, 1918, p. 87). The cabins have long since disappeared, but the district still retains its name. Figure 9 shows the location of the patented claims and names those workings that could be identified as unpatented claims in the Park City district. Only a few lead-silver prospects are found outside this district, the largest of which is the Atkins on the north side of Deerhorn Creek (pl. 1).

The district was most active from 1905 to 1910; no lead-silver deposits were mined in 1959, nor had anything but the most cursory development work been done since 1920. Some of the lead-silver deposits were examined briefly in 1910 by Bancroft (1914, p. 203–210) and all of them in 1913 by Pardee (1918, p. 86–102). In 1959 most of the adits were caved at the mouth, and the greater part of the workings were inaccessible.

The lead-silver deposits are small, and production has been recorded from only two properties. Pardee (1918, p. 88) reported being told

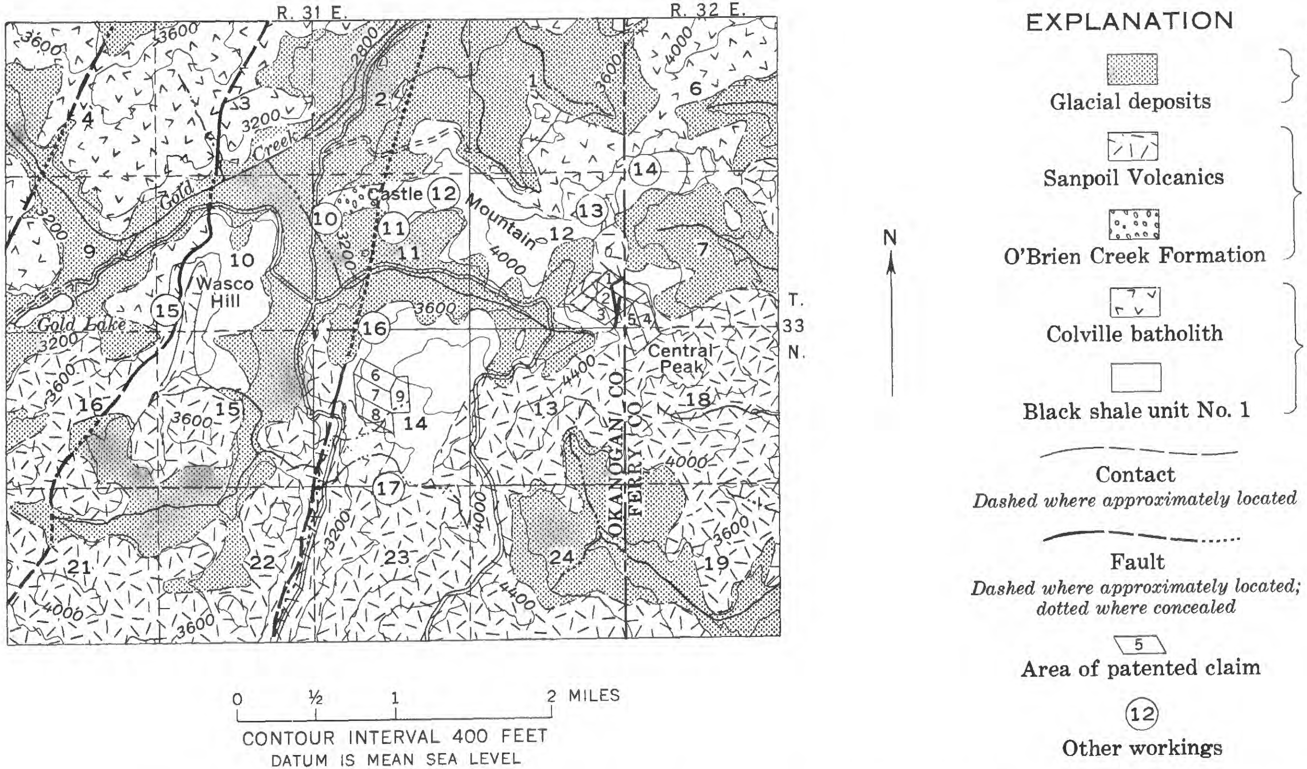


FIGURE 9.—Generalized geologic map showing the location of mining properties in the Park City district. Patented claims: (1) Park, (2) Tip Top, (3) Apex, (4) Central, (5) Monument, (6) Gertrude, (7) Sulphur, (8) Ramore, (9) Gladore. Other workings: (10) Sharp and Balthus, (11) Poorman, (12) Mountain Boy, (13) Summit and Snowshoe, (14) Eureka, (15) Wasco, (16) Iron Dike, (17) Independent.

that 4 or 5 carloads of lead-silver ore averaging $60 a ton were shipped from the Mountain Boy mine. Pardee estimated the value of this ore at $4,800. Patty (1921, p. 190) reported that 50 tons of a silver-rich galena ore was produced from the Summit claim. The value of this ore at 1920 prices would be $3,300. Hence, the total reported production of this district is only $8,100.

Development work on the lead-silver deposits, as reported by Pardee (1918, p. 93–102), Bancroft (1914, p. 205–210), and Patty (1921, p. 191), consists of many surface pits, 2 shafts each 40 feet deep, and 17 tunnels having 6,200 feet of workings on 11 claims. Some of this development work is very difficult to find because of inaccurate land descriptions due to inadequate base maps used by Pardee, Bancroft, and Patty and because of thick vegetation.

ORE DEPOSITS

The lead-silver veins are found either along or near the contact between the Colville batholith and black shale, pyllite, or limestone—for examples, the Wasco, Gladore, Ramore, Snowshoe, and Summit properties (fig. 9). The eastern part of the Park City district, which has the greatest concentration of prospects in the quadrangle, includes Castle Mountain and the mountain to the south. The area is bounded on the north by the batholith, has a cupola of the batholith to the south, and is probably completely underlain by the batholith. The evidence supporting this belief is (1) the presence of quartz monzonite in the Ramore tunnel on the Gladore claim (fig. 9), 2,200 feet northeast of the nearest surface outcrops of the batholith, and (2) the highly fractured and folded structure of the black shale in other parts of this area, which was probably deformed by the intrusion of the batholith.

The position of the veins near the contact of the batholith and shale, phyllite, or limestone is commonly controlled by small faults. In places small faults occur along this contact, as in the Hercules tunnel on the Ramore claim. Veins are reported as occurring along faults in the Atkins, Eureka (Pardee, 1918, p. 98), Independent (Pardee, 1918, p. 100), Sharp and Balthus (Pardee, 1918, p. 97), and Summit (Bancroft, 1914, p. 206) mines. Many of the other veins may also lie along small faults whose signs of movement are either not readily apparent or are concealed by the vein filling. Faulting continued in the area after the veins were formed. In the Mountain Boy mine, the ore was brecciated by postmineralization movement (Bancroft, 1914, p. 207). The best example of faulting occurring after vein emplacement is found in the small tunnel on the Sharp and Balthus claim (fig. 9), where a 4-foot vein striking N. 80° E.

and dipping 45° NW. is cut off on a fault striking N. 55° E. and dipping 45° SE.

The lead-silver veins in the Park City district have diverse attitudes (table 7). This diversity is to be expected where rocks are fractured by an underlying intrusive. Ore bodies are extremely variable in size, ranging in length from a few inches to about 200 feet and in width from a few tenths of an inch to 7 feet; however, most are less than 100 feet long and 2 feet wide. Ore bodies are of two types—quartz veins and mineralized shear zones. Quartz veins are commoner and of a higher grade than shear zones. The veins are largely quartz and contain either sparsely scattered sulfide minerals or small layers or shoots of sulfide minerals. The veins generally swell and pinch, and the ore minerals are generally confined to the wider parts. Bancroft (1914, p. 207) described the quartz veins on the Mountain Boy property, one of the two properties having any recorded production, as "varying in width from half an inch to 18 inches and in length along the dip and strike from 2 inches to 30 feet." The longest and widest veins, such as the Atkins (table 7) and the Sharp and Balthus, do not necessarily contain more sulfides than do small veins. In shear zones, the ore minerals occur generally in scattered patches throughout the zone and make up only a small part of each zone (Bancroft, 1914, p. 205–210; Pardee, 1918, p. 95–102).

The following sulfide minerals were found in the lead-silver deposits of the Bald Knob quadrangle: Pyrite, galena, sphalerite, chalcopyrite, pyrrhotite, tetrahedrite, molybdenite, arsenopyrite, bornite, chalcocite, covellite, and an unknown silver mineral. The mineralogy of the individual deposits is given in table 8. Pyrite is the most abundant sulfide and is found in all deposits. Galena is next in abundance and is the principal ore mineral in all the veins and shear zones except the Iron Dike, where sphalerite is the principal sulfide. Sphalerite is as widely distributed as galena but is generally not as abundant. A little chalcopyrite is found in most deposits. In a few very scantily mineralized veins, such as the Maid of Erin, chalcopyrite and pyrite may be the only sulfides. Pyrrhotite occurs in about half of the deposits but is common only at the Iron Dike. Minor amounts of tetrahedrite have been reported in four deposits (Bancroft, 1914, p. 206–208, 210). No other sulfide is found at more than two deposits, and with the exception of arsenopyrite, all are scarce in the deposits in which they are found. Quartz, as noted previously, is the chief gangue mineral. Other gangue minerals are fluorite, calcite, and sericite, but these minerals are not common even at the few deposits in which they are found.

TABLE 7.—*Attitude and dimensions of the lead-silver veins and shear zones*

[This table was compiled chiefly from data of Bancroft (1914, p. 205–210) and Pardee (1918, p. 95–102) but contains some new data by me]

Property	Location	Exposed length (ft)	Width (ft)	Strike	Dip	Remarks
Atkins	SW¼SW¼ sec. 12, T. 34 N., R. 31 E.	200	2.5–5	N. 9° E.	49° SE.	Vein exposed at surface.
Do	do	100	5–8	N. 43° E.	Vertical	Same vein as above; in tunnel.
Eureka	North slope of Central Peak, NW¼NW¼ sec. 7 and SW¼SW¼ sec. 6, T. 33 N., R. 32 E.	10	1.5	Northeast	45° SE.	Vein.
Gladore [1]	Center of sec. 14, T. 33 N., R. 31 E.	70	10	N. 20° W.	30° NE.	Do.
Independent	North boundary of sec. 23, T. 33 N., R. 31 E.		5	N. 30° W.	86° SW.	Shear zone.
Iron Dike	SE¼SW¼ sec. 11, T. 33 N., R. 31 E.		4	East		Do.
Maid of Erin	SE¼ sec. 1, T. 34 N., R. 31 E.		.1–3	N. 10° W.	40° NE.	Quartz vein.
Mountain Boy	NE¼ sec. 11, T. 33 N., R. 31 E.	.2–30	.5–1.5			Veins in westernmost upper tunnel.
Do	do		1.5	N. 47° E.	60° NW.	Veins in easternmost upper tunnel.
Do	SE¼SE¼ sec. 2, T. 33 N., R. 31 E.	47	.3–1.1	N. 74° E.	70°–80° NW.	Vein in Bungalow tunnel.
Poorman	West end of Castle Mountain, NW¼NE¼ sec. 11, T. 23 N., R. 31 E.		.5–1.5	N. 15° E.		Quartz vein.
Ramore [2]	NE¼SW¼ sec. 14, T. 33 N., R. 31 E.	180	5	Northeast	45° NW–vertical	Shear zone.
Do	do		.2	N. 65° W.	65° SW.	Vein.
Sharp and Balthus	NW¼NW¼ sec. 11, T. 33 N., R. 31 E.	50	.3–7	N. 77° E.	60° NW.	Do.
Snowshoe	NE¼ sec. 12, T. 33 N., R. 31 E.		2–3	East	5°–10° S.	Do.
Summit	do	50	1.5			Shear zone.
Wasco	Wasco Hill, SW¼SW¼ sec. 10, T. 33 N., R. 31 E.	60	1	N. 30°–40° W.	15°–40° NE.	Quartz vein in small shaft.
Do	do	50	3	Northwest.	65° NE.	Quartz vein 300 ft north of shaft.
Do	do		<1	Northeast	40° SE.	Quartz vein near vein north of shaft.
Do	do		2	N. 60°–70° W.	45°–55° NE.	Quartz vein in adit.

[1] Adit on this claim is called the Ramore tunnel by Bancroft (1914, p. 208).
[2] Adit on this claim is called the Hercules tunnel by Bancroft (1914, p. 208).

Twelve polished sections of ore samples from six properties were studied by T. G. Lovering (written communication, 1960), and his conclusions are summarized as follows: Not all the minerals mentioned above occurred in the polished sections. A generalized paragenetic sequence from the data available is given in figure 10. Arsenopyrite was found in only two polished sections from one deposit but in these sections it was the earliest mineral present. Pyrite is the earliest mineral in all other polished sections and occurs as large irregular masses or in small scattered cubes, which are corroded by other sulfides. Pyrrhotite occurs commonly as irregular masses but

TABLE 8.—*Mineralogy and metal content of the lead-silver deposits*

[Tr, trace. The mineralogy given in this table was compiled from data obtained by Bancroft (1914, p. 205-210), Pardee (1918, p. 95-102), and by me (taken mainly from dump specimens). The metal contents given in this table were obtained entirely from Bancroft and Pardee]

Property	Gangue minerals	Sulfide minerals	Number of assays	Ounces per ton—		Lead (percent)
				Gold	Silver	
Atkins	Quartz	Pyrite, galena, sphalerite, pyrrhotite.	1	Tr	2	
Eureka	Quartz	Galena, pyrite, chalcopyrite.	1		[1] 150.6	[1] 41.4
Gladore [2]	Quartz, fluorite, calcite, sericite.	Galena, sphalerite, pyrite, pyrrhotite, tetrahedrite, molybdenite, chalcopyrite.	4	0.05–0.07	13–59	2.7–9.6
Independent		Pyrite, galena, sphalerite.	1	Tr	1.32	
Iron Dike [3]		Sphalerite, pyrite, pyrrhotite, chalcopyrite.	2	[1] Tr	[1] 0–Tr	
Mountain Boy	Quartz	Pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, chalcocite, covellite.	9	[1] .01–.10	[1] 7.0–182	
Poorman	Quartz	Pyrite, galena, sphalerite.	0			
Ramore [4]	Quartz, fluorite	Galena, sphalerite, pyrite, chalcopyrite, pyrrhotite, tetrahedrite.	0			
Sharp and Balthus.	Quartz, carbonate mineral.	Galena, pyrite, pyrrhotite, sphalerite, chalcopyrite, bornite.	0			
Summit	Quartz, sericite	Galena, sphalerite, pyrite, arsenopyrite, chalcopyrite, tetrahedrite, unknown silver mineral.	6	[1] Tr–.08	[1] 4.95	[5] 48.3
Wasco	Quartz, fluorite	Galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, molybdenite.	0			

[1] Assay was made on a selected specimen.
[2] Adit on this claim is called Ramore tunnel by Bancroft (1914, p. 208).
[3] Zinc, 3.2–6 percent; copper, 0.05–0.3 percent.
[4] Adit on this claim is called the Hercules tunnel by Bancroft (1914, p. 208).
[5] Only one of the six samples was assayed for lead.

in places has well-formed crystal faces. Two generations of quartz were noted in some specimens. The first generation has well-formed crystals and formed either just after the pyrite or contemporaneously with the first part of the time during which sphalerite, chalcopyrite, and galena crystallized. The second generation of quartz formed after all the primary sulfides crystallized. The order in which sphalerite, chalcopyrite, and galena crystallized is not systematic; in general, they appear to have crystallized at about the same time. Chalcopyrite occurs as crystals formed by direct crystallization and as small blebs exsolved from pyrite, and these two forms may have crystallized at different times. Chalcocite was found in only one specimen from the Mountain Boy property and is probably primary, as it occurred as inclusions in galena. The unknown silver mineral

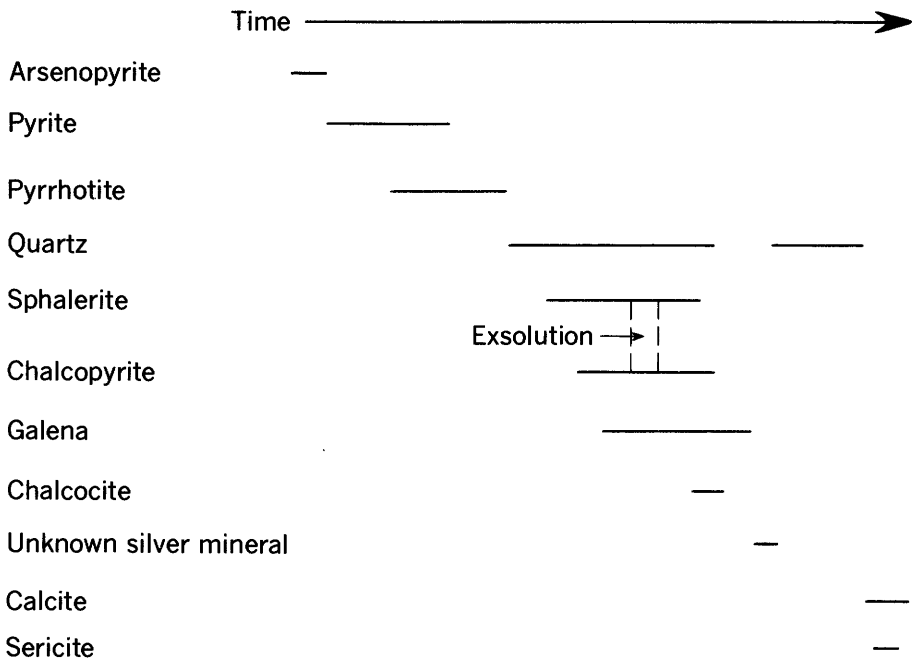


FIGURE 10.—Paragenetic diagram for primary vein minerals.

was also found on only one property—Summit—where it also occurs in small inclusions in galena. Owing to the small size of these inclusions, this mineral could not be identified by microchemical tests. A specimen of galena in which this mineral was found was qualitatively analyzed by means of X-ray fluorescence by Isidore Adler of the U.S. Geological Survey; the analysis was made by traversing an area of a specimen in which the unknown mineral occurred. Adler (written communication, 1958) reported the presence of lead, zinc, and silver. He stated: "A traverse across the selected area is suggestive of a distinct silver mineral on the edge of the galena area. The inclusions are too small, however, to make it possible to identify this mineral."

Assays of ore from the lead-silver deposits are scanty, and the few known assays were given by Pardee (1918, p. 95–102) and Bancroft (1914, p. 206–209). Most assays were made for silver and gold, a few for lead, and only two for copper and zinc (table 8). The gold ranged from a trace to 0.10 ounces per ton; the silver, from 0 to 182 ounces per ton; the lead, from 2.7 to 40.3 percent; the copper, from 0.05 to 0.3 percent; and the zinc, from 3.2 to 6 percent. As the only two samples assayed for copper and zinc came from the deposit in which these elements were most abundant (Iron Dike property), the assay figures given above for these two elements are probably close to maximums for the district. Some of these assays are of veins of little economic value. The richer veins, such as some found on the Mountain Boy, Summit, and Gladore prospects, may contain 0.04–0.08 ounces of gold per ton, 20–90 ounces of silver per ton, 20–40 percent lead, and small amounts of zinc and copper.

CHROMIUM-NICKEL DEPOSITS

Several small chromium-nickel veins are found in a northeast-trending belt about 2½ miles long between Parmenter Creek and the ridge to the east of Stepstone Creek. The deposits occur either in serpentine or in metamorphosed sedimentary rocks adjacent to serpentine. Figure 11 shows the location of the principal prospects; a few other prospects have been described in this area by Pardee (1918, p. 85) but could not be located. Two of the deposits, the Stepstone and the one in the SE¼ sec. 12, T. 32 N., R. 30 E., are in carbonate rocks; the Jumbo is mostly in silicified phyllite, and the Idell is in serpentine. Most of the workings consist of shallow pits, but two caved adits are on the Jumbo claim, and a small vertical shaft and a small inclined shaft are on the Stepstone claim. No production has been recorded from any of these properties.

The chromium-nickel deposits consist generally of quartz veins ranging from a fraction of an inch to 1 foot in thickness and contain some sulfides and chromite. At the Stepstone claim (fig. 11), however, where the country rock is dolomite, the sulfides and chromite lie in a carbonate gangue. Some of the deposits, such as the Idell, consist of small quartz veins containing small amounts of secondary nickel minerals. Exposures are generally poor, and the chromium-nickel veins can rarely be traced beyond the pit in which they are exposed.

The best exposed chromium-nickel veins, and probably the largest deposit, is on the Stepstone claim (fig. 11). The veins are from ⅛ – 1½ inches thick and are anastamosing. The rocks exposed next to the veins on this property are silicified phyllite, silicified serpentine, and limestone altered to dolomite. Most of the veins are in the upper 4 feet of the dolomite, where they are generally parallel to the bedding. The chief ore mineral is chromite; lesser amounts of pentlandite and chalcopyrite are also present. Gangue minerals are dolomite, calcite, and quartz; quartz is found in only a few veins. Pardee (1918, p. 84) reported that "seams and surfaces bear thin efflooresence-like coatings of genthite, an apple-green silicate of nickel and magnesium." The X-ray pattern of this mineral, however, indicates that it is annabergite ($Ni_3As_2O_8 \cdot 8H_2O$). Annabergite was plentiful on the dump and at all other properties examined. Erythrite ($Co_3As_2O_8 \cdot 8H_2O$), the pale-pink cobalt analog of annabergite, was seen on one

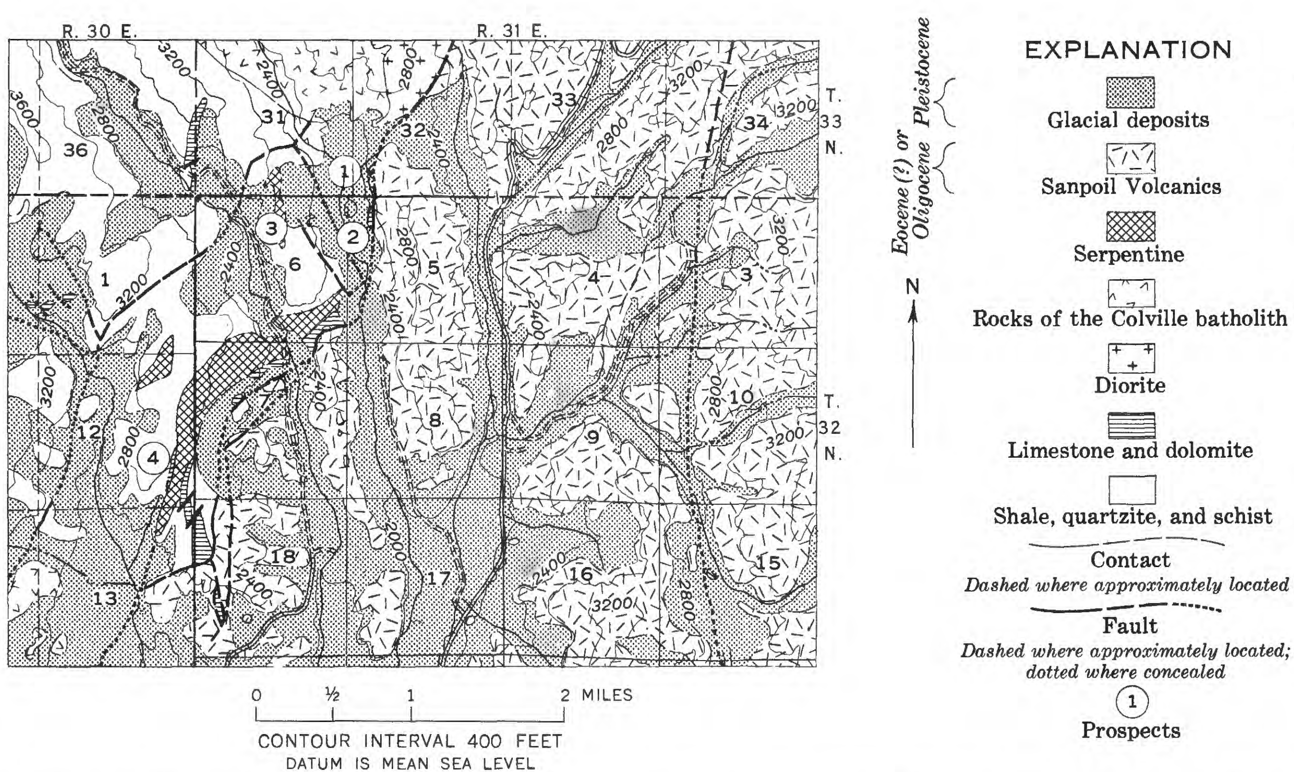


Figure 11.—Generalized geologic map showing the location of the principal chromium-nickel prospects. Prospects: (1) Jumbo, (2) Stepstone, (3) Idell, (4) name not known.

specimen from the Stepstone dump. A weighted average of three 5-foot channel samples across the veins in the inclined shaft was reported by Huntting (1956, p. 278) to be 1.22 percent Ni and 2.97 percent Cr_2O_3. A specimen of unoxidized ore collected by Pardee (1918, p. 84) contained 2.65 percent Ni.

The serpentine was intruded along the contact between the phyllite and the overlying dolomitized limestone. The large Long Lake fault is 150 feet east of the chromium-nickel veins. Late-stage fluids may have moved up along this fault, silicified the serpentine and some of the phyllite, and altered the limestone to dolomite. The ore minerals were apparently deposited either at the same time or somewhat later.

PLACER DEPOSITS

Small gold placer deposits were mined in the Bald Knob quadrangle in the early 1900's. The gold was evidently derived from somewhere in the Strawberry Creek basin, as the placers lie along Strawberry Creek, on Gold Creek below its junction with Strawberry, and on the West Fork of the Sanpoil River below its junction with Gold Creek. Pardee (1918, p. 103) stated that in 1913 a chain of placer claims extended from the mouth of Strawberry Creek to the mouth of the West Fork of the Sanpoil River. The placers were not rich, and in panning tests made by Pardee (1918, p. 103) along the West Fork of the Sanpoil River and Gold Creek, the greatest amount obtained from a single pan was estimated to be worth 0.005 cents. Collier (1907, p. 68) found that in the richer sand near the mouth of the West Fork of the Sanpoil there was about 4 cents worth of gold per cubic yard. In 1959 all signs of old placer workings had disappeared except along the West Fork of the Sanpoil for about a quarter of a mile above its mouth, where large piles of gravel suggest that this was the most productive area.

Production data on the placers in the Bald Knob quadrangle are meager, and all that is recorded is $100 worth of gold produced from a placer owned by Harry Crounse near the mouth of Strawberry Creek (Pardee, 1918, p. 103).

GEOLOGIC HISTORY

The pre-Jurassic geologic history of the Bald Knob quadrangle is difficult to decipher because some of the older rocks were replaced by later batholithic rocks, others were covered by Tertiary volcanic rocks, and the rest were partly covered by Pleistocene glacial debris.

In the late Paleozoic or early Mesozoic time the quadrangle was submerged by a sea that extended northward into British Columbia and southward possibly as far as Nevada. Into this sea were deposited great thicknesses of mud and sands; in some places the sediments were deposited in sorted thick layers; in other places, in sorted thin layers, or in poorly sorted layers. These sediments are represented at present by phyllite, shale, quartzite, phyllitic quartzite, schist, and graywacke. In small isolated areas limy muds and sands, which are now represented by impure limestone lenses, were deposited with these clastic sediments. During deposition basalt flows were extruded on the sea floor and buried by later sediments. The flows are represented in the Bald Knob area by the greenstone exposed along the west side of the West Fork of the Sanpoil River. Other flows have been found by Pardee (1918, p. 144) in the eastern part of the Colville Indian Reservation and by S. J. Muessig (oral communication, 1958) in the Republic quadrangle.

Some time after the sediments were laid down, they were intruded by several small diorite bodies, which later became metadiorites. Following the emplacement of the diorite, but before the batholith was emplaced, the entire region was deformed; northwest-trending faults and northward-trending folds were formed, and the sedimentary and igneous rocks were metamorphosed. The metamorphism was low grade, and a green schist facies was formed in those rocks that reached equilibrium.

The metamorphic rocks, which enclose the earlier metadiorite, were intruded by a later diorite, which in the Bald Knob quadrangle formed all or part of two stocks, and then by the Colville batholith. In some areas the metamorphosed sedimentary rocks in a narrow contact zone were crumpled and further metamorphosed. In some areas hydrothermal fluids, concentrated within the batholith as it crystallized, rose and formed small lead-silver deposits either along the contact of the batholith or along small fractures in the overlying metamorphosed sedimentary rocks.

Some time after the Colville batholith was intruded, long northeast-trending faults started to form. Movement on these faults may have started in Late Cretaceous time and continued until at least Miocene time. Some time after movement started on these faults, dikes of dunite were intruded into the metamorphosed sedimentary rocks in the southwestern part of the quadrangle; the largest dike was intruded along one of these faults. Later, the dunite dikes were altered to serpentine. Hydrothermal fluids, rich in chromium, iron, and nickel, were concentrated as these dikes crystallized and formed small chromium-nickel deposits in the dikes and adjacent wallrock.

A long period of erosion followed the intrusion of the batholithic rocks, and much of the cover over these rocks was removed. As the Sanpoil Volcanics is thickest near the line now occupied by the present Sanpoil River, the ancestral channel of this river, and possibly some of the other major streams, formed during this time. Sometime during this period of erosion, probably in Eocene time, a long period of volcanism started during which showers of pyroclastic material resulted in the deposition of the O'Brien Creek Formation. Most of the pyroclastic material formed air-laid tuffs, but in a few places breccias and, where small lakes were present, water-laid tuffs were formed. Volcanism was greater north of the Bald Knob quadrangle, as these basal pyroclastic deposits are much thicker in the Republic and Wauconda quadrangles (Muessig and Quinlan, 1959). After the O'Brien Creek Formation was deposited, a thick series of rhyodacite or quartz latite flows, the Sanpoil Volcanics, was deposited; in places these flows contain tuff beds, evidence indicating that explosive eruptions continued intermittently.

From Eocene to Oligocene time the flows and tuffs of the thick Sanpoil Volcanics continued to be deposited. These volcanics were deposited largely in the Republic graben, which formed between the northeast-trending Scatter Creek fault zone to the northwest and the northeast-trending Sherman fault to the southeast. Movement on the faults bounding the graben continued during the eruption of the volcanics, and the graben sank slowly into the space from which the magmas had come. Irregular tilting during subsidence deformed the volcanic rocks in some places.

During and after the emplacement of the volcanic rocks, a long period of erosion took place, during which time the upthrown blocks of the graben were worn down in places to the level of the downthrown block and the land surface reached a mature stage of erosion. Probably in late Pliocene time, the land was again uplifted, and the streams were rejuvenated. The streams cut steep-sided valleys into the older, mature land surface.

During Pleistocene time one or more continental glaciers moved southward across the Bald Knob quadrangle and deposited a mantle of till, which was thickest in the valleys and thinnest on the ridge tops. When the ice began melting, it melted first from the uplands and left tongues of ice along the valleys. In places along the sides of some of these tongues, kame terraces were formed, and in a small lake dammed by an ice tongue near the mouth of Gold Creek, lake sediments were deposited. Erosion has continued since the disappearance of the ice and has stripped most of the till from the uplands.

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